Modeling Supply Response with Implicit Revenue Functions: A Policy-Switching Procedure for Rice

Dean T. Chen and Shoichi Ito

An econometric method of estimating implicit revenue with a policy switching mechanism is proposed for supply response analysis. The model develops important linkages between farm program instruments and commodity market equilibrium and allows evaluation of supply response decisions under conditions of major policy shifts. The econometric procedure developed here is applied to the U.S. rice sector to determine program compliance/noncompliance decisions under three alternative rice program periods. A change in farm prices was found to affect significantly producers' net returns and participation rate. Results indicate price impacts on acreage planted are inelastic for program participants but elastic for nonparticipants.

Key words: implicit revenue, policy switching procedure, rice programs, supply response.

Conventional economic theory provides little guidance in the specification of agricultural supply response models with government intervention. A pure profit maximization framework assumes perfectly competitive markets for which government policy influences generally are ignored. An empirical model, on the other hand, can be less restrictive using proxy policy variables as supply shifters; however, such specification offers only limited help in identifying key program instruments and the complex process that determines producers' crop production decisions.

Policy modeling work is further complicated by frequent changes in agricultural legislation and by increasing complexities in program administration. It could be argued that a new econometric model is needed to adequately investigate supply response each time provisions of government programs are changed. It has been suggested that a methodology be considered for combining time-series data from periods governed by several combinations of farm commodity programs (Just, Lucas).

The purposes of this paper are, first, to develop econometric modeling techniques by incorporating a consistent framework of implicit revenue functions and a policy switching procedure for supply response analysis and, second, to investigate producers' behavior in response to changes in expected net operating returns for both program participants and nonparticipants. The policy-switching procedure consists of equations that (*a*) estimate operating returns over variable costs (OROVC) incorporating different program provisions over time, then (*b*) utilize OROVC to estimate supply response relations. By using the switching procedure, acreage response equations over different farm programs are combined in a system to account for changes in model specifications under conditions of major policy shifts. The econometric methods developed here are applied to the U.S. rice sector to examine the sensitivity of the model to changing farm programs for policy evaluation purposes between 1961 and 1990.

Previous Supply Response Models

The importance of government intervention in determining producers' crop production decisions has been a subject of much empirical investigation (Askari and Cummings). Among numerous econometric models estimated for major

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Texas Agricultural Experiment Station Technical Article No. 29001. The research was supported in part by CED, Economic Research Service, U.S. Department of Agriculture through a cooperative agreement, Project No. 58-3 AEK-8-00019.

The authors wish to thank Warren R. Grant, C. Richard Shumway, and three anonymous *Journal* referees for their many valuable comments and suggestions on an earlier draft and Jason Ming-Che Chien for computational assistance.

Review coordinated by Steve Buccola.

program crops, there exist three major approaches in modeling supply response for policy evaluation purposes. The first approach uses direct inclusion of key program variables such as acreage allotments and diversion payments per acre, either as explanatory variables in the model (Garst and Miller) or as dummy intercept shifters for program years (Lidman and Bawden).

The second and perhaps most widely adopted approach uses composite policy variables as advanced by Houck and Ryan in the early 1970s. They utilized the effective support price and effective diversion payment rate as the key theoretical arguments. Although the Houck-Ryan approach is considered a useful framework for empirical applications, the approach is restrictive on both theoretical and empirical grounds. From a theoretical viewpoint, separate treatment of output price, effective support price, and diversion payment variables can be considered ad hoc at best. On empirical grounds, inherent statistical estimation problems such as multicollinearity and simultaneous equation bias exist. Moreover, several important features of the 1981, 1985, and 1990 farm bills and other potential policy instruments cannot be explicitly treated by this approach. Several studies related to the Houck-Ryan formulation include risk analysis (Just; Morzuch, Weaver, and Helmberger; Brorsen, Chavas, and Grant), price expectations (Gardner, Romain, Lopez), and multi-input, multiproduct regional investigations (Shumway, Shumway and Alexander).

The third approach, initiated in the early 1980s, utilizes a revenue-cost approach. Lee and Helmberger proposed an alternative to the effective price support/diversion payment variables by constructing a feed grain program payment variable based upon program participation incentives derived from price support loans, deficiency payment rates, acreage set-aside requirements and diversion payments, and other incentives. This specification explicitly evaluated revenue from program participation, although it failed to combine program payments with output price into a total revenue variable. Salathe, Price, and Gadson explicitly determined the level of farm participation in acreage set-aside and diversion programs and total acreage planted by program participants and nonparticipants based upon producers' expected net return per acre using a large-scale agricultural sector model, the Food and Agricultural Policy Simulator (FAPSIM). This approach, which combines output price and government payments, was found to be particularly useful in determining program participation rates and the set-aside, diverted, and planted acreages. Finally, Love developed the program payment and participation rate formulation of acreage response for wheat based on the revenue approach.

The major weakness of the first two approaches is the absence of a cohesive and broadly conceived conceptual framework for linking farm program instruments to commodity market equilibrium. These models also fail to provide a mechanism for explicit determination of farm program instruments such as the loan rate, target price, and loan repayment rate. The third approach, the revenue and program participation rate framework, partially corrects this weakness. Recently, the implicit revenue function (IRF) approach was developed for cotton (Chen) and for wheat (Chen, Penson, and Teboh) based on the two kinds of revenues considered in the model: revenues generated from the crop actually produced (i.e., cash receipts from marketings and deficiency payments) and revenues that are not necessarily related to actual produced output (i.e., diversion payments, grazing revenue from idled land, interest charges, and storage costs paid by the government). This approach incorporates the price-supporting, income-supplementing, and output-restricting features of U.S. farm policies and program participation decisions into a structural model context.

Building on the IRF approach, this paper proposes a switching procedure, which incorporates operating returns over variable costs to reflect major changes in U.S. farm programs over time. Given such a system, it is possible to combine several alternative acreage response specifications to reflect different policy regimes. The following section discusses the derivation of the implicit revenue functions for producers, the specification for acreage response equations with regard to three rice program periods, and a description of the policy-switching mechanism.

The Model and Procedure

The U.S. rice model presented here is a complete sectoral model of thirty-six simultaneous equations comprising five major blocks to determine the following: implicit revenue functions (or operating returns over variable costs); farm program payments and government costs; farm price and incomes; acreage, yield, and production; and demand and inventory stocks. For the purpose of this paper, no detailed model description is intended. Instead, a brief description of the policy-switching procedure and the related acreage response equations for rice are provided.[1]

Derivation of Implicit Revenue Functions

The implicit revenue function facilitates estimation of producer's operating returns over variable costs (OROVC) for each of the simulation periods when rice programs were substantially changed. A major benefit of using the IRF is that it is possible to avoid multicollinearity problems that frequently occur among the explanatory variables. That is, the IRF reduces the number of independent variables in each equation by incorporating important factors such as farm prices, target prices, loan rates, loan repayment rate, and acreage reduction rates into one variable, the OROVC [see equation (1)]. As a result, this formulation also saves degrees of freedom, an important advantage to policy modeling work when there are only a small number of observations. Further, by focusing on the revenue and cost factors incorporated into the OROVC rather than stated explicitly as a separate variable for each policy instrument, it is possible to perform a policy analysis over different program periods with a single theoretical framework.

To derive OROVC for acreage response analysis in this study, three historical rice program periods are considered. From 1961 to 1975, rice programs basically consisted of price support and acreage allotment. The marketing quota was also proclaimed, although it was suspended in 1974 and subsequent years (Holder and Grant, Johnson et al.). During the second period (1976–81), target price and loan rate were implemented beginning with the 1976 crop. All direct benefits of the program, however, were allowed only to the allotment holders.

The third and latest period, 1982–90, regulates U.S. rice programs under the 1981 and 1985 farm bills. During this period, the allotment was repealed while the target price and loan rate system was continued (Johnson et al.). The base acreage concept was introduced in the 1981 farm bill, and program participation became voluntary, with acreage reduction required. In 1983, the PIK (payment-in-kind) program was implemented in order to reduce large surpluses (USDA 1983). Under the 1985 farm bill, in particular, the marketing loan and the 50/92 option helped expand U.S. rice markets while cutting domestic production (Glaser).

The key features of the government programs in each period are explained and summarized in table 1. Elements affecting revenues for program participants are described in sections A, B, and C of the table for the rice program periods of 1961–75, 1976–81, and 1982–90, respectively. These elements are categorized under P, Y, Q, and S in the tables. Based on those elements, the general formulation of IRF in terms of OROVC (operating returns over variable costs at the farm level) can be written in matrix notation as follows:[2]

$$R = P'YQS, \tag{1}$$

where R is a unit vector of returns over variable costs per acre (equivalent to OROVC); P, an $n \times 1$ vector of prices, implicit revenues, and costs per unit; Y, an $n \times n$ diagonal matrix of yield, program payment yield, and others; Q, an $n \times n$ diagonal matrix of planted area for program payments; and S, an $n \times 1$ vector of operating function for the government program provisions.

Because Y and Q are diagonal matrices, all elements off the diagonal in these matrices are equal to zero. The OROVC for the rice programs before 1982 can be estimated fairly simply as shown in table 1, A and B. The rice programs for the 1982–90 period governed by the 1981 and 1985 farm bills (table 1, C) are the most complex, and the process of calculating the OROVC during this period is explained in detail below.

The top row of table 1, C for period 1982–90 indicates cash receipt per one base acre for the program participants when *PF* (farm price) under the P matrix is multiplied by *SY* (yield per acre) of Y matrix, 1-*KARP*-*KPLD*-*C*3*0.3 of Q matrix, and 1 of S matrix. For example, in 1983, a 15% acreage reduction (*ARP*) was imposed on the participants. In addition, a 5% paid land diversion (*PLD*) and the PIK program were optional participation choices after the *ARP*. To calculate the OROVC per one base acre for the participants, it is assumed in this study that the participants enrolled in all of the options. Thus, the planted acreage rate is one base acre subtracted by the rates of *ARP*, *PLD*, and the rate of PIK in which an additional 10% to 30% reduction was required.[3]

[1] A detailed description of the entire model is available from the authors upon request.

[2] Equation (1) also can be rewritten as: $R = \Sigma_{i=1} p_i y_i q_i s_i$, where p_i, y_i, q_i, and s_i are column/diagonal elements of P, Y, Q, and S, respectively.

[3] In this research, the PIK participants are assumed to set aside the maximum (30%) of the base acreage, which approximates the actual situation.

Table 1. Policy Parameters for Three Rice Program Simulation Periods

Revenue/Cost Components	Price, Cost, and Payment Rate (*P*)	Yield Unit (*Y*)	Acreage Unit (*Q*)	Policy Option Operators (*S*)
A: From 1961 through l975				
Cash receipts	*PF*	*SY*	1	*A*1
Loan payments	MAX(*PS*,*PF*) − *PF*	*SY*	*ALLOT*/*BASE*	1
Variable costs	*PVC*	−1	1	*A*1
B: From 1976 through 1981				
Cash receipts	*PF*	*SY*	1	1
Def. payments	*PT* − MAX(*PL*,*PF*5)	*SYG*	*ALLOT*/*BASE*	1 − *B*1
Loan payments	MAX(*PL*,*PF*) − *PF*	*SY*	*ALLOT*/*BASE*	1 − *B*1
Disaster payments	*k***PT*/3	*SYG**.75	*ALLOT*/*BASE*	1 − *B*1
Variable costs	*PVC*	−1	1	1
C: From 1982 through 1990				
Cash receipts	*PF*	*SY*	1 − *KARP* − *KPLD* − *KPIK*	(1 − *C*1){*C*2 + *C*3*(1 − *C*2)*0.50}
Def. payments	*PT* − MAX(*PL*,*PF*5)	*SYG*	1 − *KARP* − *KPLD* − *KPIK*	(1 − *C*1){*C*2 + *C*3*(1 − *C*2)*0.92}
Loan payments	MAX(*PL*,*PF*) − *PF*	*SY*	1 − *KARP* − *KLPD* − *KPIK*	*C*2 + *C*3*(1 − *C*2)*0.50
Marketing loan premium	*PL* − *PAW*	*SY*	1 − *KARP* − *KPLD* − *KPIK*	*C*2 + *C*3*(1 − *C*2)*0.50
Diversion payments	*PDVG*	*SYG*	*KPLD*	1
PIK payments	*PF*	*SYG**0.8	*KPIK*	1
Disaster payments	*k***PT**0.33	*SYG**0.75	1 − *KARP* − *KPLD* − *KPIK*	1 − *C*4
Variable costs	*PVC*	−1	1 − *KARP* − *KPLD* − *KPIK*	*C*1 + (1 − *C*1){*C*2 + *C*3*(1 − *C*2)*0.50}
Maintenance costs for diverted land	*PMC*	−1	*KARP* + *KPLD* + *KPIK*	1
Maintenance costs for 50/92	*PMC*	−1	1 − *KARP* − *KPLD*	*C*2*(1 − *C*2)*0.50
Revenue from grazing on diverted land	*PGZ*	1	*KARP* + *KPLD* + *KPIK*	1

Note: These tables show matrices to calculate operating returns over variable costs per one base acre under the different farm programs during 1961 and 1990. The definitions of variables in table 1 parts A, B, and C are: *ALLOT* is allotment acreage; *BASE*, base acreage (the greater of planted acreage or total allotment acres for years prior to 1982); *k*, insurance value coefficient; *KARP*, rate of acreage reduction; *KPLD*, rate of paid land diversion; *KPIK* = 0.3 in 1983 indicating the PIK program in 1983, otherwise 0 (assuming producers cut back an additional 30% under the PIK); *PAW* is USDA-announced world adjusted price (U.S. annual average, $/cwt); *PDVG*, U.S. average paid land diversion payment rate ($/cwt); *PF*, U.S. average producer price, crop year average ($/cwt); *PF*5, U.S. average producer price during August through December for payment calculation ($/cwt); *PGZ*, revenue from grazing on diverted land ($/acre); *PL*, U.S. average loan rate ($/cwt); *PMC*, maintenance cost ($/acre); *PS*, U.S. average government support price ($/cwt); *PT*, U.S. average target price ($/cwt); *PVC*, U.S. average variable cost ($/acre); *SY*, U.S. average yield (cwt/acre); *SYG*, U.S. average program payment yield (cwt/acre); *A*1 = 0.99 if marketing quotas are imposed, otherwise 1 (marketing quotas were suspended in 1974 and subsequent years); *B*1 = 1 if *PF*5 > *PT* indicating the allotment system is practically not a restricting factor for rice production; *C*1 = 1 if *PF* 5 ≥ *PT*, otherwise 0; *C*2 = 1 if year is earlier than 1982 and if *PF*5 ≥ *PVC*/*SY* indicating no participation in the 50/92 option, otherwise 0; *C*3 is participation coefficient for the 50/92 option; and *C*4 = 0 if disaster payments are declared, otherwise 1.

If *PL* ≤ *PAW*, the *PL* − *PAW* = 0. Prior to 1986, *PAW* = *PL*. The PIK program was implemented in 1983. The features were to encourage producers to cut production acreage by another 10% to 30% (or whole base under bidding) in addition to the regular 15% of ARP and 5% of paid land diversion. The acreage diverted due to the PIK was paid in-kind with 80% of the established program yield.

The second row of table 1, C is for calculating the deficiency payments. First, the deficiency payment rate is defined under the *P* matrix. The deficiency payment rate is the difference between the target price and the higher either of the loan rate or the five-month average farm price.[4] Accordingly, *C*1 in *S* matrix is zero with deficiency payment, and one without deficiency payment, respectively. Deficiency payments are paid on government program yield (*SYG*). Planted acreage under the *Q* matrix is the same as that for cash receipts. The value of *C*1 for the policy option operator under the *S* matrix will be 0 if *PF*5 < *PT* indicating deficiency payments are paid, or 1 if *PF*5 ≥ *PT* indicating no deficiency payments. *C*2 and *C*3 are policy option operators for the 50/92 option. Accordingly, the de-

[4] If the average farm price of the first 5 months (Aug.–Dec.) of the marketing year is equal to or higher than the target price, then there are no deficiency payments.

ficiency payments per one base acre would result by multiplying each item in P, Y, Q, and S matrices, i.e.:

$$(PT - MAX(PL, PF5))*SYG*(1 - KARP - \mathrm{KPLD} - \mathrm{KPIK})*(1 - C1)*(C2 + C3 *(1 - C2)*0.92).$$

Following the same manner, a value in each row is calculated, then added (or subtracted for the cost items) and estimated for the OROVC per one base acre for the program participants. In this study, the fixed costs are not considered. For supply response analysis, the profit-maximization framework is built upon marginal conditions for which an exclusion of the fixed costs may not be a serious omission. This is particularly true when the relative profitability measurement is employed in the model in determining program compliance and noncompliance decision.

For nonparticipants, the calculation of OROVC is straightforward. The corresponding unit values under individual P, Y, Q, and S matrices for cash receipts would be PF, SY, 1, and 1, respectively. Because nonparticipants do not have to set aside any area, their planted acreage would be the whole base acre with a unit of 1. Variable costs are also applied for the whole one base acre. Of course, no government payments are applied for nonparticipants. Thus, the OROVC for nonparticipants are calculated with cash receipts subtracted by variable costs.

Note that the IRF incorporates the expectation term. It is critical for producers to formulate expectations in order to decide whether or not to participate in the program. Under the 1981 and 1985 farm bills, in particular, the government announces target prices, loan rates, and other program provisions in advance so that producers can formulate their expectation of OROVC.

Acreage Response Prior to 1981 Farm Bill

The rice programs under farm bills prior to the 1981 farm bill were less complicated. Based on the IRF formulation, the OROVC for the allotment holders and nonholders are calculated. Data for acreage planted by the allotment holders and nonholders are not available, however. Interestingly, planted acreage during 1961–73 was always slightly lower than allotment acreage.[5] The allotment system essentially was suspended between 1974 and 1981 because of supply shortages and high market prices. Therefore, it may not be too far off from the real situation if it is assumed that all rice producers were under some government protection during 1961 and 1981. Under this assumption and applying the Nerlovian partial adjustment model (Nerlove),[6] a stochastic equation for acreage planted during 1961–81 may be estimated as a function of lagged one period planted acreage, SA_{-1}, and expected OROVC:

$$(2) \qquad SA1 = f_1(SA_{-1}, E(OROVCAD)),$$

where *OROVCAD* implies OROVC for producers under the government programs (i.e., program participants). This specification with the simple formulation of the IRF should sufficiently capture the key program instruments implemented in the rice programs prior to the 1981 farm bill.

Acreage Response Under Recent Farm Bills

Modeling acreage response under the 1981 and 1985 farm programs is much more complicated, requiring a step-by-step procedure employing several equations. Once the OROVC per one base acre for both program participants and nonparticipants are calculated, it is possible to estimate the participation rate for the rice program in a stochastic equation. The participation rate is calculated in terms of base acreage planted by the participants to the total base acreage at the national level. Because program participation rate is ranged between 0 and 1, it is important to employ a logistic transformation of the function for estimation. The logit model (Pindyck and Rubinfeld) is particularly suitable for this type of estimate.[7] The participation rate in the form of a logit model would be regressed as specified:

$$(3) \quad LOGITR = f(E(OROVCAD - OROVCNO)/OROVCAD),$$

where $LOGITR = \log(RPRM/(1 - RPRM))$, *RPRM* is the participation rate in the program, and *OROVCAD* and *OROVCNO* are the operating returns over variable costs for the program

[5] During this period, marketing quotas were implemented. The penalty for violating quotas was quite detrimental to producers (Holder and Grant). This may be why planted acreages did not exceed the allotment acreages during this period.

[6] In the Nerlovian partial adjustment model, expected market price is used. In this research, however, expected price term is replaced by expected operating returns over variable costs (OROVC).

[7] A logit model is specified as $P_i = 1/(1 + e^{-(\alpha+\beta X_i)})$, or $\log(P_i/(1 - P_i)) = \alpha + \beta X_i$, where P_i is the probability that an individual will make a certain choice, given knowledge of X_i (Pindyck and Rubinfeld, pp. 287–300).

participants and nonparticipants, respectively. This relative profitability measurement is expressed in an expectation term for the coming year. It is logical that the more profitable it is for the participants in a coming year, the higher would be the participation rate for that year. Once the *LOGITR* is determined, it is necessary to normalize it back to the form of participation rate (*RPRM*):

$$(4)\qquad RPRM = \text{Exp}(LOGITR)\,(1 + \text{Exp}(LOGITR))^{-1}.$$

Given the determination of program participation rate, the base acreage for both participants and nonparticipants can be derived:

$$(5)\qquad SBPRM = RPRM*SB$$

$$(6)\qquad SBNO = (1 - RPRM)*SB,$$

where *SBPRM* is base acreage for the participants, *SBNO* is base acreage for nonparticipants, and *SB* is exogenously determined total base acreage. To take into account the base acreage concept as the key planting decision variables, equations for acreage planted by the participants and nonparticipants would be specified:

$$(7)\qquad SAAD = f_2(SBPRM, KARP + KPLD, KPIK)$$

$$(8)\qquad SANO = f_3(SBNO, E(OROVCNO/OROVCOT)),$$

where *SAAD* is acreage planted by the participants, *KARP*, *KPLD*, and *KPIK* are the percentages of acreage set-aside under ARP, PLD, and PIK programs, respectively, *SANO* is planted acreage of the nonparticipants, and *OROVCOT* is the operating returns over variable costs of competitive crops. Nonparticipants have the flexibility to allot a portion of rice land to other crops that may be more profitable than rice. The specification of equation (8) is also in expectation terms. Accordingly, total acreage planted (SA2) can be defined as an identity, a sum of the planted acreages of participants and nonparticipants:

$$(9)\qquad SA2 = SAAD + SANO.$$

These seven equations [(3)–(9)] for acreage response under the 1981 and 1985 farm bills allow us to evaluate program participation rate, acreages planted by participants and nonparticipants, and total acreage planted. Further, the whole system with these specific program equations allows us to evaluate government costs.

Switching Procedure

To combine alternative acreage response equations for the whole period from 1961 through 1990, a policy-switching procedure is employed in this study using *S*1 and *S*2 to combine equations (2), (7), and (8):

$$(10)\qquad SA = S1*(f_1(SA_{-1}, E(OROVCAD)) + S2*(f_2(SBPRM, KARP + KPLD, KPIK) + f_3(SBNO, E(OROVCNO/OROVCOT))),$$

where *S*1 is 1 during 1961–81, otherwise 0; *S*2 is 1 during 1982–90, otherwise 0. The function f_1, as expressed in equation (2), represents acreage responses by all producers during the early rice program period (1961–81), while functions f_2 and f_3, as expressed in equations (7) and (8), represent acreage responses by the program participants and nonparticipants during the recent farm programs (1982–90), respectively.[8]

In these nine equations [(2)–(10)] all of the explanatory variables are endogenously determined except for *SB* (total base acreage), *KPIK* (rate of payment-in-kind diversion program in 1983), *KARP* (rate of acreage reduction), and *KPLD* (rate of paid land diversion), which are all exogenously determined. *RPRM* in equation (3′), together with identities (5) and (6), is used to simultaneously determine *SBPRM* and *SBNO*. (This is reported in the empirical results section.) These variables are also incorporated as part of the explanatory variables in equations (7′) and (8′). The equation system described above is critical to analyze not only a producer's behavior over time but also the impacts of change in prices on program participation rate, acreage planted, revenues for the participants and nonparticipants, and government costs.

Price Elasticities and Impacts

Impacts of a 1% increase in farm price can be simulated using the simultaneous equation model to evaluate magnitudes of effects of a price increase on major endogenous variables over various program periods. With a 1% increase in farm price, the model simulation results provide a useful comparison to conventional elasticity estimates with respect to farm price calculated from single equations.

The impact elasticity of price in this research is mathematically derived using the chain rule:

[8] Liu et al. employed an endogenous switching system in their dairy study. Their switching system, in particular, refers to probabilities of market equilibrium solution and government support solution during the same government program period.

$$(11)\qquad \xi_{p,SA1} = \frac{\partial SA1}{\partial R}\frac{\partial R}{\partial PF}\frac{PF}{SA1},$$

where $\xi_{p,SA1}$ is own-price elasticity (or impact) of acreage response in the IRF method, and R is operating return over variable cost (OROVC). A change in farm price (PF) initially affects the OROVC. Then, the change in OROVC affects program participation rate and, ultimately, total acreage planted. This sequential effect of prices on producer supply response behavior can be traced by the system of equations.

In essence, a method employed by Grant, Beach, and Lin and Jolly, Fielder, and Traylor is a direct elasticity estimation on a single equation basis:

$$(12)\qquad \xi_p = \frac{\partial SA}{\partial PF}\frac{PF}{SA},$$

where ξ_p is an own-price elasticity with respect to farm prices. Because crop production decisions are affected not only by farm price but also by the entire operating returns over costs, the acreage response elasticity (or impact elasticity) derived in this research provides some insights into the complex process of making planting decisions in response to government support.

For the 1982–90 program period, impacts on participation rate, acreages planted by the program participants and nonparticipants, and total acreage planted with respect to a 1% increase in farm price are derived as follows:

$$(13)\qquad \xi_{p,SAAD} = \frac{\partial SAAD}{\partial RPRM}\frac{\partial RPRM}{\partial R_{AD}}\frac{\partial R_{AD}}{\partial PF}\frac{PF}{SAAD},$$

$$(14)\qquad \xi_{p,SANO} = \frac{\partial SANO}{\partial(1-RPRM)}\frac{\partial(1-RPRM)}{\partial R_{NO}}\frac{\partial R_{NO}}{\partial PF}\frac{PF}{SANO}, \text{ and}$$

$$(15)\qquad \xi_{p,SA2} = \frac{SAAD}{SA} * \xi_{p,SAAD} + \frac{SANO}{SA} * \xi_{p,SANO} \left(0 \le \frac{SAAD}{SA} \le 1 \text{ and } 0 \le \frac{SANO}{SA} \le 1\right),$$

where definitions of the variables are the same as explained above except for: $\xi_{p,SAAD}$ and $\xi_{p,SANO}$ are impacts on acreages planted by the program participants and nonparticipants, respectively; R_{AD} and R_{NO} are operating returns over variable costs for the participants and nonparticipants, respectively; and $\xi_{p,SA2}$ is impacts on the total acreage. Equations (13) and (14) indicate that a change in farm price affects operating returns over variable costs, which then affects the participation rate. Finally, a change in participation rate affects acreages planted by participants and nonparticipants. The two impacts on participants and nonparticipants are weighted proportionately by planted acreages and added to derive the total impact elasticity of national acreage planted [equation (15)].

Data

Data used in this study are crop year annual basis at the U.S. aggregate level from 1961 through 1988 and were collected from various publications of the U.S. Department of Agriculture. They are *Rice Situation and Outlook Report, Crop Production Report, Agricultural Outlook, World Supply and Demand Estimates, Economic Indicators of the Farm Sector: Costs of Production,* and *Agricultural Statistics*. Missing data were generated by regressing the available data against individual correlated variables. Production costs data prior to 1975, for example, are not available; therefore, costs data during 1961–74 were estimated by regressing costs against price index of all fertilizers based on data during 1975–88.

Empirical Results

The complete simultaneous equations system has seventeen stochastic equations and nineteen identities. The behavior equations were estimated using OLS, while the entire system was simultaneously solved using the Gauss-Seidel method. Among the four equations reported below, jointly dependent variables appear on the right-hand side. They are: operating returns for participants and nonparticipants, *OROVCAD* and *OROVCNO*, respectively, and participation rate in logit model, *LOGITR*, which is converted to normal participation rate, *RPRM*, in order to determine base acreage for the participants and nonparticipants, *SBPRM* and *SBNO*, respectively. These endogenous variables are simultaneously solved by the overall model. Major exogenous variables in the model include rates of acreage reduction program (*KARP*), paid land diversion program (*KPLD*), payment-in-kind diversion program (*KPIK*), and a comprehensive set of program instruments such as target price, loan rate in determining operating returns per acre. The simulation performance of the model provides significant results in tracing the effects of alternative government rice programs and allows evaluation of major policy shifts over time.

Because of its purpose and brevity, this paper presents the estimated results of the acreage response-related equations only. The estimated equations for acreage planted for the earlier farm program period, program participation rate, and acreage planted by the participants and nonparticipants under the 1981 and 1985 farm bills during 1982 and 1988, are as follows (definitions of variable names are basically the same as explained in table 1, and t-values are in parentheses):

$$(2') \quad SA1 = \underset{(2.26)}{513} + \underset{(5.75)}{0.655}*SA_{-1} + \underset{(3.57)}{2.11}*OROVCAD_{-1} - \underset{(3.35)}{3082}*KPIK$$

$$R^2 = 0.851 \qquad R^2\text{adj.} = 0.862 \qquad \text{DW} = 1.93 \qquad \text{Durbin } h. = 0.17,$$

$$(3') \quad LOGITR = \underset{(6.47)}{7.853}*KPIK + \underset{(15.8)}{1.734}*((OROVCAD - OROVCNO)/OROVCAD + (OROVCAD_{-1} - OROVCNO_{-1})/OROVCAD_{-1})$$

$$R^2 = 0.850 \qquad R^2.\text{adj.} = 0.819 \qquad \text{DW} = 2.15,$$

$$(7') \quad SAAD = \underset{(0.344)}{104} + \underset{(9.25)}{1.04}*(SBPRM) - \underset{(10.1)}{4806}*(KARP + KPLD) - \underset{(15.6)}{3560}*KPIK$$

$$R^2 = 0.989 \qquad R^2\text{adj.} = 0.978 \qquad \text{DW} = 1.68,$$

$$(8') \quad SANO = -\underset{(2.97)}{325} + \underset{(3.53)}{0.640}*SBNO + \underset{(3.38)}{394}*(OROVCNO + OROVCNO_{-1})/(OROVCSY + OROVCSY_{-1})$$

$$R^2 = 0.941 \qquad R^2\text{adj.} = 0.902 \qquad \text{DW} = 1.53.$$

The estimated coefficients for independent variables are all significantly different from zero at the 5% significance level. The Durbin-Watson or Durbin h statistic for equations with lagged endogenous variables indicates no serious serial correlations in an error term. The estimation period for acreage planted prior to the 1981 farm bill [equation (2′)] was extended to 1983 in order to improve reliability of estimation.[9] In this equation, a dummy for the 1983 PIK program is included as an explanatory variable. The statistical result of this equation indicated that the one-year lagged OROVC is superior to the current OROVC or combination of both. This may be because producer planting decisions up to around 1981 tended to depend heavily on the information available from the previous crop year. In the period, acreage planted to rice was constrained by allotment systems and marketing quotas up to 1973. During 1974–81, market prices were higher than support/target prices. Although government payments were available only for allotment holders, farm prices higher than the target prices tended to upstage dependence on government support prices during this period. Accordingly, during the period up to 1981, the producer's revenue from the previous year appeared to be a better source than government support prices affecting producers' expected revenue and planting decisions.

On the other hand, equation (3′) for the rate of program participation in the logit model was improved by incorporating the current OROVC. After 1981 (under the 1981 and 1985 farm bills), farm prices have been substantially lower than target prices. Most rice producers are eligible for government programs which are announced in advance of the planting season; therefore, producers tend to depend on current expected operating returns under the government programs while being influenced by the results of the previous year. This is particularly evident in estimating program participation rate [equation (3′)] and acreage planted by nonparticipants [equation (8′)] during the 1982–88 period. Program participation rate [equation (3′)] was estimated with a dummy for the PIK program (*KPIK*) and a relative level of profitability of

[9] This extension was done because equation (2) was estimated by a general specification that is applicable to the whole period, including the 1981 and 1985 farm bill periods.

compliance to noncompliance in government programs, as measured by the difference of expected operating returns over variable costs for program participants (*OROVCAD*) and nonparticipants (*OROVCNO*) divided by *OROVCAD* during current and previous years. The statistically significant estimates in equation (3′) imply that a decision of rice acreage is influenced by both the previous year's and the current expected OROVC's.[10]

Once participation rate is estimated, planted acreage by the program participants [equation (7′)] is expressed by the national total base acreage for the participants, a sum of acreage reduction rate and paid land diversion rate, and a dummy for the 1983 PIK program. Acreage planted by the nonparticipants [equation (8′)] is estimated by the base acreage of the nonparticipants and the relative expected return of rice (*OROVCNO*) to soybeans (*OROVCSY*), which is the major competitive crop for rice, during the current and previous years. Using the switching procedure in equation (10), the estimated equations (2′), (7′), and (8′) are combined into one equation in the system for the whole period from 1961 through 1988.

The magnitudes of estimated impacts are reported in tables 2 and 3. Impacts with respect to farm prices are estimated during different rice programs. The estimated impact of price on acreage response for the 1981 crop in this study is larger at 0.29 than elasticities estimated by Grant, Beach, and Lin (0.13) and Jolly, Fielder, and Traylor (0.16) for the 1982 and 1979 crops, respectively (table 2). The difference between the results of this study and others may be due to the means of calculating elasticities.

The impacts of a 1% increase in farm price for operating returns over variable costs (OROVC) to the allotment holders and nonholders for the 1981 crops were estimated to be 2.20 and 2.36, respectively (table 3). This implies that as farm price increased by 10%, OROVC increased by 22% and 23.6% for al-

[10] Current expected OROVC is calculated based on current program provisions, such as target prices, loan rate, loan repayment rate, and expected farm price.

Table 2. Comparison of Elasticities with Respect to Own Price

	Chen and Ito (1981 crop)	Grant, Beach, and Lin (1982 crop)	Jolly, Fielder, and Traylor (1979 crop)
Acreage Planted	0.29	0.13	0.16

Note: Jolly, Fielder, and Traylor did not report elasticities; therefore, elasticities were calculated based on their estimated farm price coefficients and 1979 data.

Table 3. Impacts of 1% Price Increase on Revenue and Planted Acreage for Three Rice Program Periods

	Earlier Programs (1981 crop)	1981 Farm Bill (1984 crop)	1985 Farm Bill (1987 crop)
Operating returns over variable cost			
Participants[a]			
Actual ($/acre)	197.93	246.44	276.69
Impact (%)	2.20	1.21	0.91
Nonparticipants			
Actual ($/acre)	185.08	143.17	143.22
Impact (%)	2.36	2.78	2.70
Participation rate			
Actual	NA	0.85	0.95
Impact (%)	NA	−0.24	−0.08
Acreage planted			
Participants			
Actual (thousand acres)	NA	2,402.00	2,333.00
Impact (%)	NA	−0.37	−0.14
Nonparticipants			
Actual (thousand acres)	NA	428.00	19.00
Impact (%)	NA	2.82	51.57
Total	0.29	0.11	0.28

[a] Participants and nonparticipants for the 1981 crop imply allotment holders and nonallotment holders, respectively.

lotment holders and nonholders, respectively. The difference between the two are negligible during the period prior to the 1981 farm bill. Under the 1981 and 1985 farm bills, however, the impact elasticities for the OROVC for the participants and nonparticipants are significantly different. While the impacts on nonparticipants remained at the elastic level (2.78 and 2.70 in 1984 and 1987, respectively), the impacts on the participants decreased sharply to 1.21 for the 1984 crop and 0.91 for the 1987 crop. This indicates that the government programs after 1981 have provided stronger support in program revenues of the participants when farm prices were much lower than target prices. On the other hand, the price impacts for nonparticipants are relatively high, reflecting the fact that revenues of nonparticipants are directly affected by market prices. The effectiveness of the government program during the recent period is also indicated by declining impacts on participation rates—from −0.24 for the 1984 crop to −0.08 for the 1987 crop. The actual participation rate in the rice program was 85% for 1984 and 95% for 1987, respectively. The inelastic price impact estimated for the 1987 crop may reflect the situation that rice producers needed to stay under government protection during the recent years of depressed market conditions.

Finally, impacts of acreage planted are also very different between program participants and nonparticipants. The estimated impacts for participants are −0.37 and −0.14 for 1984 and 1987 crops, respectively, while those for nonparticipants are 2.82 and 51.57 in the two crop years, respectively (table 3). This implies that, although it is more difficult for producers to exit the program over time, they still tend to leave the program as market price increases, rendering a decrease in acreage planted by participants. Accordingly, when farm prices increase, acreage planted by nonparticipants tends to increase as producers tend to stay out of the program, changing from participating to nonparticipating. The large impacts estimated for acreage planted by nonparticipants for the 1987 crop, 51.57%, may reflect its small acreage base of 19,000 acres, compared with 428,000 acres in 1984, because of introduction of the marketing loan under the 1985 farm bill. Because the marketing loan allowed the market price to drop substantially, it was much harder for producers to stay out of the government program than before.

Since decisions by the participants and nonparticipants regarding acreage planted are in opposition, the impact of total acreage planted reflects the net effect of these two and are estimated to be 0.11 and 0.28 for the 1984 and 1987 crops, respectively (table 3). Comparing the magnitude of impacts of acreage planted under earlier programs (pre-1981) to recent farm bills (1981 and 1985 farm bills), the impact during the pre-1981 farm program appears to be greater. This may reflect a situation of high farm prices and freedom to expand acreage during the pre-1981 farm program period.[11] On the other hand, the acreage response relationship for the recent farm bills has been under the heavy influence of government programs because of low farm prices, and producers are apt to be inflexible and restricted within the program provisions.

Conclusions

The implicit revenue function approach applied for this supply response study shows promise in providing a comprehensive set of program instruments for agricultural policy analysis. This study also demonstrates the utility of a switching procedure that allows evaluation of supply response behaviors for time periods governed by multiple farm programs in a system of equations. Empirical results from this research compare favorably with those of similar studies. In addition, the model provides significant results and valuable insights on producers' acreage response behavior through the program participation decisions.

[Received June 1989; final revision received May 1991.]

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[11] During the 1973–81 period, farm prices were higher than support/target prices, and there were no governmental restrictions to acreage planted.

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