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PERSPECTIVES ON COMPETITIVE BIDDING: RETIREMENT OF ENVIRONMENTALLY SENSITIVE FARMLAND

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Perspectives on Competitive Bidding:
Retirement of Environmentally Sensitive Farmland

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Abstract

The USDA has used bidding to enroll land into the Conservation Reserve Program (CRP) and may use similar mechanisms to implement other policy instruments in which some or all agricultural land cropping rights are acquired to protect or increase environmental amenities. Experience with the CRP suggests that current enrollees are being compensated in excess of the lowest payment they would be willing to accept in exchange for loss of cropping rights. While it may be prohibitively expensive to estimate such reservation prices on all potential CRP parcels, it is likewise difficult to design a bidding mechanism that induces landowners to reveal these values.

While the competitive bidding and contingent valuation literatures provide some guidance, the problem of designing a cost effective bidding mechanism for land retirement does not conform precisely to situations in which theoretical, experimental or case study results have been reported. Despite this, realistic incremental changes in the CRP's current bidding mechanism that induce competitive behavior among bidders appear to portend significant savings in government outlays.

I. Introduction

Cropland retirement has been used as an instrument of agricultural policy since the 1950s and is likely to be a fixture of future policy as long as U.S. agricultural productive capacity is perceived to exceed demand. One current incarnation of this instrument is the Conservation Reserve Program (CRP), in which landowners offer bids for retiring highly erodible land for ten years in exchange for annual payments.

As concern over the federal budget has increased, those government programs (such as the CRP) that involve large public or private expenditures have been subject to increasing cost effectiveness scrutiny. While agricultural programs have been relatively immune from such scrutiny compared to other domestic programs, their high cost is increasing pressure for making them more cost effective as well.

This paper focuses on proposed improvements to CRP enrollment procedures, particularly on cost-effectiveness gains achieved by modifying bidding procedures. We describe the current CRP bidding mechanism Section (II) and estimate potential savings to the government if the bidding mechanism was improved (III). We next present an analytic framework for evaluating the cost effectiveness of alternative bidding mechanisms (IV). In Section V, we summarize the bidding literature relevant to possible reform of the CRP. Then we develop a general land retirement bidding model (VI) and discuss several extensions making it more realistic (VII). We suggest some implications of this model to the CRP (VIII) and, finally, suggest directions for future research (IX).

II. Current CRP Bidding Mechanism

The Conservation Reserve Program, authorized under Title XII of the 1985 Food Security Act (the farm bill), is a hybrid of previous land retirement and soil conservation programs, with some novel features.[2] Under the CRP, farmers agree not to produce crops on qualifying highly erodible (or otherwise eligible) land for ten years, in exchange for annual rental payments. During announced enrollment periods, farmers submit bids to their county USDA Agricultural Stabilization and Conservation Service (ASCS) office indicating the acreage and annual payment per acre that they would accept in compensation for retiring the

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[2]The CRP has several stated legislative objectives. (1) Conserve soil productivity for future generations. (2) Improve surface and ground water quality by reducing runoff and use of farm chemicals. (3) Reduce environmental damages associated with wind erosion. (4) Improve wildlife habitat quantity and quality and increase ecological diversity. (5) Provide a guaranteed income supplement to farmers. (6) Reduce surplus crop production.

land. The ASCS later announces the Maximum Acceptable Rental Rate (MARR) for the multi-county pool in which the bidder's farm is located. All parcels bid at that level or lower are accepted for enrollment. The Soil Conservation Service (SCS) verifies that the parcel fulfills erodibility and other requirements and prepares a management plan for permanent vegetative cover. Land cover costs can receive 50% government cost-sharing.

An evaluation of the cost effectiveness implications of changing the CRP's current bidding mechanism requires that we first examine its salient features. Of particular importance are the variables that the government has chosen to induce and to evaluate bids: land parcel eligibility criteria, MARR values, (often multiple county) bidding pools, the number of bidding periods, county acreage enrollment limits, and national acreage enrollment goals. Significantly, the CRP has no stated budget limit at either the pool or national levels.

Physical eligibility criteria are intended to ensure that enrolled land is "highly erodible" or is otherwise environmentally sensitive. (More recent eligibility criteria include riparian land and cropped wetlands.) In this sense, the purpose of eligibility criteria is to guarantee a minimum level of conservation benefits from land retirement.

Bidding pool boundaries are rough proxies for cash rent value isolines, such that eligible land in each pool is <u>relatively</u> homogeneous in terms of value of agricultural production. The MARR is a pool-specific, per-acre amount (loosely based on the 1985 average local cash rents), above which bids are not accepted. Imposing the MARR tends to limit at the upper end the productivity of land that is retired within a given pool. However, because the MARR could lead to rejection of a bid in one pool that might have been accepted in an adjacent pool, individual MARRs do not impose a national ceiling on the productivity of retired land.

The CRP has had multiple bidding rounds of fixed and known length during which landowners may submit bids. Given the CRP's novelty and scope, it was unlikely that the national acreage enrollment goal would be met after just one round. Multiple rounds have given landowners time to learn about and become accustomed to the program and to observe bid acceptances in previous rounds. This learning allowed landowners to revise their bids downward, if initially rejected, or to enter bids more likely to be accepted, even if they did not bid in earlier rounds. From the government's perspective, multiple rounds have spread out the workload, while allowing the government to modify program provisions to make bidding more or less attractive in order to meet the national enrollment goal.

The 40-45 million acre enrollment goal set by Congress was based upon estimates of the national acreage of highly erodible land, as well as that amount of land in production that was perceived to result in the surplus of agricultural commodities that concerned policymakers at the time the program was established. The existence of this statutory enrollment goal has meant that program success has been largely measured on the basis of how many acres are retired, not upon the progress toward stated program objectives (Dicks).

Within each county, no more than 25% of the cropland acreage can be retired. This provision is intended to limit adverse effects on the local agricultural economy, especially agricultural input suppliers. This local acreage limit has not, it appears, been used overtly to induce competition among potential bidders. As well, the government has not overtly used national or local budget limits as control variables; there is only an implicit upper level of government outlays associated with the national enrollment objective, MARRs, and county enrollment limits.

Gross CRP outlays which will run into the tens of billions of dollars, must be arrayed against partially compensating budget savings. For each acre retired, a farmer's eligibility to receive government commodity program benefits is also reduced by some fraction of an acre. As well, reduced crop production presumably leads to increased market prices, which also reduces necessary government subsidies. Because the attractiveness of CRP participation is affected by other farm program parameters, commodity program rules can be construed as indirect CRP control variables. However, <u>net</u> federal government outlays with the CRP are still billions more than without the CRP (Young and Osborn).

The decision to bid land into the CRP is thought to be influenced by many factors such as land quality, commodity program participation, the proportion of the farm remaining will be affected, age of farmer (Esseks and Kraft, 1990). In addition, the CRP may be attractive to risk averse producers because: 1) annual CRP rent is fixed, 2) CRP entry provides a subsidized opportunity to comply with conservation compliance, 3) overall yield risk is reduced if marginal land is retired, and 4) there is opportunity to earn greater off-farm income (Boggess). On the other hand, the CRP locks farmers in to a ten year contract; breaking it imposes penalties.

The minimum per acre bid level is determined by the value to the farmer of the net returns that would be foregone by retiring the bidded parcel. This opportunity cost or "reservation price" is, in turn, thought to vary according to crop yields, relative mobility of factor inputs, landowner expectations of future crop prices, etc. In later analysis, we assume that each landowner knows her reservation price; however, the opportunity costs of foregone crop production over the ten year period are subject to several types of uncertainty:

1. optimum production process and other control variables;

2. stochastic processes such as yields, input and output prices, interest rates, and other variables for which probability distributions can be estimated;

3. government program variables under existing legislation (but determined in future) such as loan rates, acreage limitations, target prices, etc.; and

4. future changes in legislation or new legislation that affect the rules of the game, that is, ease of or returns to participation in the future (Boggess, 1986).

Landowners have had access to numerous sources of information on how to calculate "breakeven" bids: articles in farm magazines, extension bulletins, staff from local government agencies, etc., and, for the first round of bidding, many farmers undoubtedly availed themselves of suggested calculation procedures. Since the first round, however, the constancy of the observed MARRS allowed farmers to peg per-acre bids directly to the local MARR. As shown in Section IV, the current CRP bidding mechanism has become tantamount to a fixed "take-it-or-leave-it" offer from the government. This has led some observers to argue that CRP participants are being paid "too much" and that the bidding mechanism would be improved through competition (GAO, 1989; Taff and Runge, 1988).

III. Empirical Estimate of Overpayment and Potential Adverse Effects

In this section, we estimate total overpayments from the CRP, as implemented, and potential savings from a yet-to-be identified perfectly incentive-compatible bidding scheme.

The demonstrated increase in average bid levels and the decrease in variation among bids over the several CRP rounds might be explained in three ways that are not mutually exclusive. First, bidding might be working as it is supposed to: low bids are accepted in earlier rounds, leaving only those farmers with higher reservation prices remaining to bid in later rounds. In this case, the observed distribution of bids in each round perfectly tracks the underlying distribution of reservation prices of those bidding in that round. (Since the bid caps were unchanged over the rounds, we need an appurtenant explanation of why everyone did not bid in earlier rounds. Convention assigns this to reasons of transaction costs and strategic behavior.)

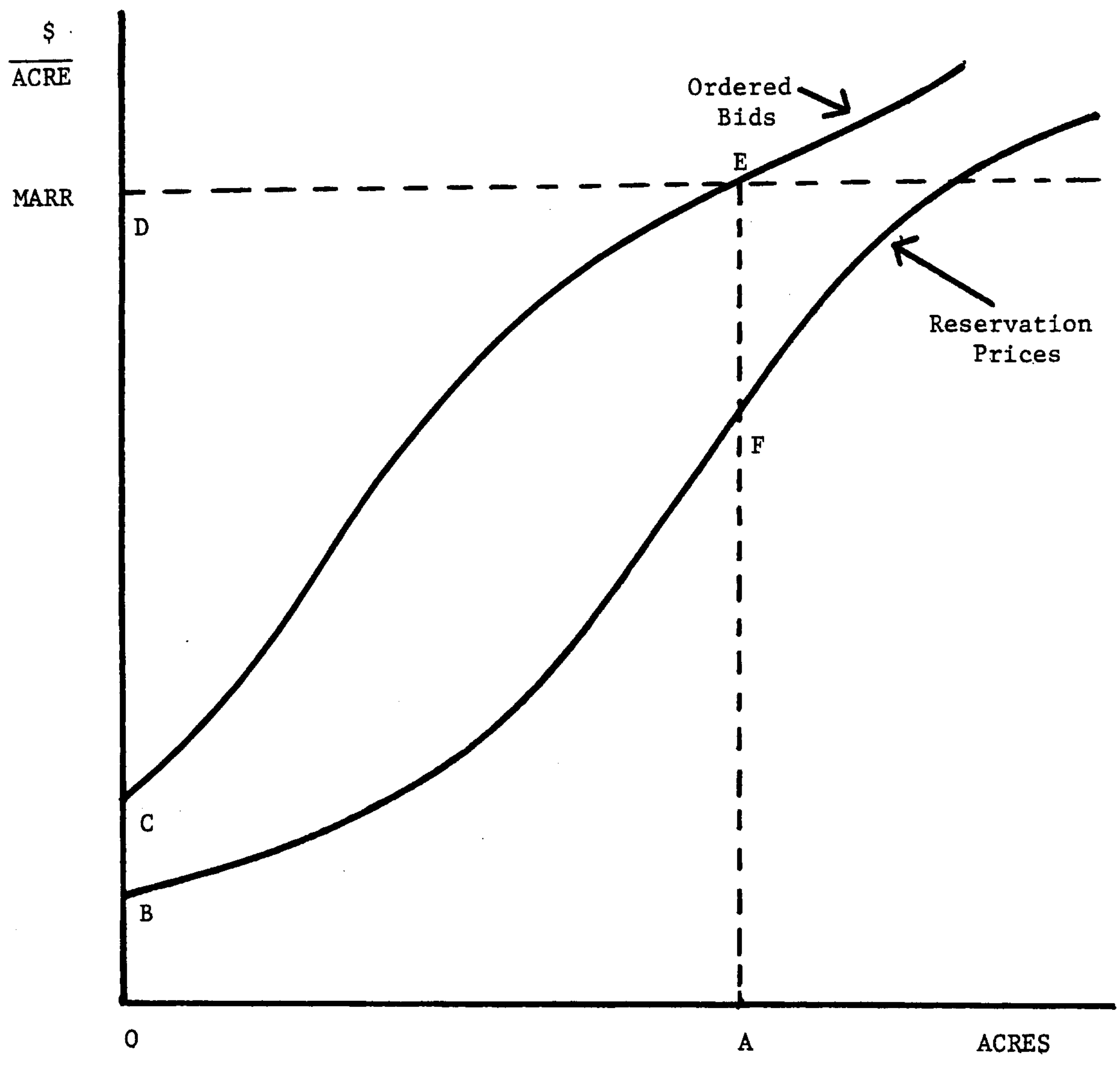
A second related explanation might be that bidders' expectations of future income opportunities to be foregone by land retirement increased over time, causing bids to be raised.

A third explanation for bids converging to the MARR is that prospective bidders (after the first round) learned that any bid no greater than the bid cap would be accepted and that the bid cap would not change from previous rounds. New bidders and previously unsuccessful bidders both learned to peg their bids to the MARR. Under this explanation, the observed distribution of bids does not accurately reflect the underlying distribution of reservation prices. In the following discussion, we adopt this behavioral explanation of bid convergence.

The actual changes in CRP bid distributions can be used to approximate the budget savings that might be achieved by a scheme that induces landowners to bid their reservation prices rather than pegging to the MARR. In Figure 1, showing a stylized cumulative distribution of bid CRP acreage, the area under the "offer curve", AOCE, is thus total government payments to enroll A acres. Had each enrollee bid the MARR instead, the government would have paid area AODE for the same A acres. The underlying reservation price distribution shows that the government would have had to pay only area AOBF, if landowners had instead bid their true reservation prices. The area between the two curves, BCEF, is thus the potential ex post "savings" (over the actual performance) achieved by a perfect preference revelation scheme, and the area between the offer curve and the horizontal MARR line, area CDE, is the actual savings achieved by the extant CRP bidding procedures compared to a fixed offer (at the MARR) scheme.

Of course, "true" underlying reservation prices are unknown to the government. In what follows, we use the bid distribution from the first round of CRP bids in Minnesota (950 bids, enrolling 64,589 acres) to approximate this distribution. This will be compared against successive rounds' offer curves to measure the potential savings achievable by better bidding systems. Since even the first round bids are probably above true reservation prices, savings estimates, so measured, are understated. On

Figure 1: Hypothetical Relationships Between Ordered Bids (Offer Curve), Unobserved Reservation Prices, and Maximum Accepted Bid (MARR) Under Competitive Bidding



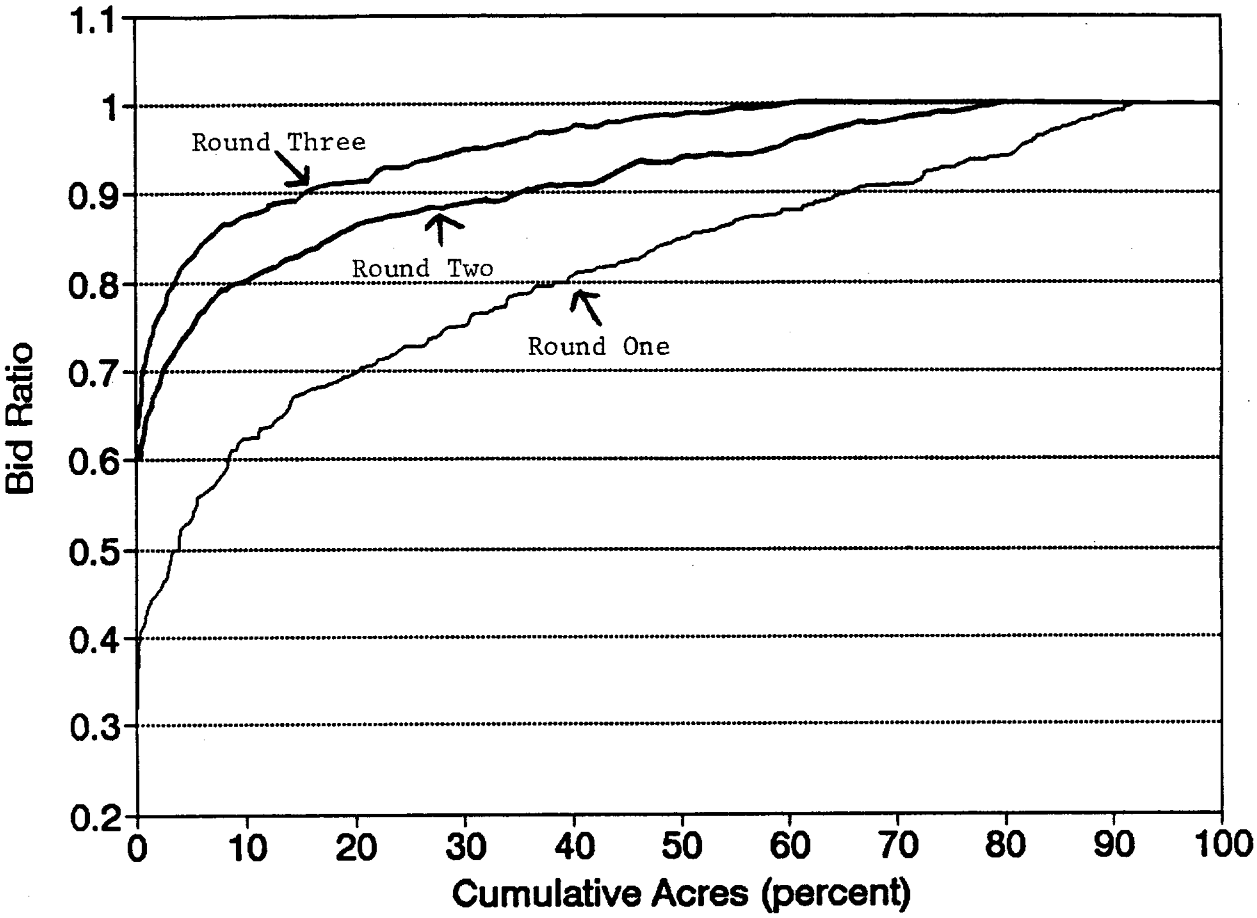
the other hand, because later round offer curves may not represent behavioral changes alone--underlying reservation price distributions unchanged over time--continued use of the first round offer curve as a baseline may lead to an overestimate of bidding savings.

Figure 2 shows the shifts in Minnesota CRP offer curves over the first 3 rounds of bidding. (Rounds 4-9 are nearly identical in shape to the third round). In order to compare offer curves across rounds and across the nine Minnesota bidding pools (each with a different MARR), the horizontal axis shows the percent of total acres accepted in each round, and the vertical axis shows the ratio of each bid to the appropriate round's MARR in place for the pool in which the land was located. Bid convergence is demonstrated by the decreasing proportion of bid acres much below a bid ratio of 1.0. (The figure shows only those bids that were accepted. "Overbids" (those above the MARR) declined precipitously after the first round in Minnesota.)

Bid Savings

Actual CRP bidding savings over a fixed MARR offer (corresponding to area CDE in Figure 1) can be approximated by summing over all bids the difference between the appropriate MARR and the accepted bid (Table 1). The second column (Fixed MARR) is generated by multiplying the enrolled acreage by the appropriate MARR, and the third is the actual CRP program expenditure (bid times acreage). The fourth column is simply the difference between the two. Savings are expressed in thousand dollars and as a percent of the fixed MARR payment. For the reasons discussed above, savings from bidding declined over the rounds, from an initial 17.79% to

FIGURE 2: CRP Offers by Bid Ratio,
Minnesota, First Three Rounds



SOURCE: USDA ASCS program records
and authors' calculations

Table 1: Actual CRP Bid Savings: Minnesota: Rounds 1-9

Round	Acres	Annual Payment (000)			
		Fixed MARR	Actual Payment	Savings	
				dollars	percent
1	64,589	3,778	3,106	672	17.79
2	158,746	8,706	8,040	666	7.65
3	298,734	17,237	16,648	589	3.42
4	671,910	41,243	39,522	1,720	4.17
5	208,573	11,528	11,314	214	1.86
6	128,128	6,806	6,614	192	2.82
7	113,162	6,302	6,071	231	3.67
8	84,234	4,846	4,684	162	3.34
9	102,279	5,825	5,622	203	3.48
TOTAL	1,830,355	106,271	101,622	4,649	4.37

less than 5%. Overall, the actual CRP bidding scheme saved $4.6 million compared to paying the MARRs for all accepted bids.

Taking the first round offer curve as the underlying reservation price distribution, we can calculate the potential savings had the CRP bidding scheme worked better. The $106.3 million sum of the second column in Table 1 represents the "worst case," a bid system that fails completely to elicit bids below the cap. If we apply the same percentage savings over the fixed offer that was actually achieved in the first round--17.79%--to each of the succeeding rounds, we obtain a potential savings of $18.9 million compared to actual savings of $4.6 million. This understates savings from a "perfect" bidding scheme to the extent that the first round offer curve is not an accurate portrayal of the underlying reservation price distribution. Savings are overstated to the extent that the underlying distribution itself shifts over the rounds, as previous enrollments altered the set of potential bidders.

This, then, provides us with an upper and lower bound to the savings that might be achieved by a given CRP bidding scheme. If the Minnesota numbers are extrapolated to the U.S., the 33.9 million acres enrolled so far might have been brought in at $223 million less than their actual $1.66 billion annual cost.[3] The present value of the ten year stream of the potential $223 million/year savings is obviously much larger. The magnitude of this "overpayment" convinces us that more careful attention is due to schemes that promise to increase government cost effectiveness.

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[3]Using a substantially different procedure, GAO estimated that competitive bidding would have saved $296 million in the Mountain and Plain States alone, through the first seven rounds (GAO, 1989).

IV. Analytical Framework for Evaluating Alternative Bidding Mechanisms

In order to make comparisons between alternative bidding mechanisms, we first need to specify the "base case" against which other bidding schemes can be compared. One option would be a world in which the CRP has not yet been implemented, so that potential participants have as little information as they did prior to the first CRP bidding round. Alternatively, one could consider a world in which the current CRP exists and is being extended, in which case potential participants would know all about MARRs and about previously successful and successful bid distributions. Clearly, a given scheme might be an improvement relative to one such base case but not to the other. In Sections VI and VII, alternative bidding schemes will be evaluated against a base of the first type, a world in which the CRP has not yet been implemented. In Section VIII, we adapt these results to provide some policy guidance for the existing conditions base case as well.

Second, we must specify whether alternative bidding mechanisms are analyzed in an optimizing framework or by comparison of discrete outcomes. While the USDA has both discrete (generic bidding mechanism) and continuous (eligibility criteria, MARR) parameters to choose, it does not appear to have been optimizing anything in particular in its implementation of the CRP to date. Landowners (potential bidders), however, have tended to behave as though maximizing income, subject to the known MARR. In this paper, we analyze a CRP-like policy instrument that is formulated, following the literature, as an optimization problem for both sides. Nevertheless, our results provide some policy guidance to the current CRP, even in its non-optimizing mode of implementation.

Third, we need to specify an accounting perspective, so as to clarify the relevant relationships among social costs, social benefits, government payments, bids, MARRs, and reservation prices. Social benefits (SB_i), as used here, are the (monetized) environmental conservation benefits accruing to society from retiring eligible parcel i. Social costs (SC_i) are the societal opportunity costs of not producing crops on the parcel. Despite the presence of a commodity "surplus," SC_i may be positive (Ervin and Dicks, 1988; Willis, et al., 1988; Kozloff and Taff, 1990). Two common tests of whether a program results in a positive net social change relative to a no-program case are $\Sigma SB_i/\Sigma SC_i > 1$ or, equivalently, $\Sigma SB_i - \Sigma SC_i > 0$. When two or more discrete programs (or bidding schemes) are being compared, however, the benefit/cost ratio test may give a different ordering than the net social benefits test. Regardless of which test is used, SB_i and SC_i are the only relevant parameters from a social accounting perspective. Unfortunately, neither are observable in CRP transactions, although might be estimated.

A government accounting perspective is appropriate for an analysis of the level of program effects in comparison to total government expenditures. Unlike the social accounting perspective, in which transfers are uncounted, under this perspective monies transferred from taxpayers to program participants influence the relative success of one program option over another. Program effects may be measured as social benefits or as constant unmonetized units of service. In some cases, the total level of service to be provided is predetermined by statute or rule, so that program options are compared according to least cost to achieve that given level of service. In other cases, the service levels of two options are compared while being constrained by the same budget. If CRP outcomes are measured in acres enrolled (A), for example, and expenditures are direct payments for retirement (GP_i), then two program alternatives could be compared on the basis of the ratio $\Sigma A/\Sigma GP_i$.

From the private accounting perspective, participants are concerned with the difference between accepted bids (BID_i) and reservation prices (break-even amounts) required in compensation (RP_i). In this sense, RP_i is the private opportunity cost of retirement, also unobserved in the CRP transaction. Because profit-maximizing farmers will never accept a smaller government payment than their reservation price, they will always submit a bid at $BID_i \geq RP_i$.

From both government and private accounting perspectives, then, "overpaying" a CRP participant for enrolling parcel i means $GP_i > RP_i$. This is obviously an unfavorable outcome for the government, but a favorable one for participants. For two bidding schemes with identical outcomes, if scheme A favors program participants more than does scheme B, then A is less favorable for the government.

Since estimating social benefits of land retirement is beyond the scope of this paper, we will emphasize the governmental accounting perspective in comparing alternative bidding mechanisms. Nevertheless, choosing the option that minimizes overpayments may also have positive social welfare effects. Overpaying farmers for CRP land retirement may directly or indirectly affect social welfare in several ways:

1) The ten year stream of program outlays is greater than it would otherwise be. This added claim on the federal budget either exacerbates the negative macroeconomic effects associated with the federal budget deficit or increases the distortions associated with taxation. In terms

of secondary effects stemming from net changes in national consumption and investment, the loss of income to taxpayers may not offset the gain in income to CRP participants from payments in excess of reservation prices.

2) To the extent that overpaying draws more land out of production than otherwise, it exerts upward pressure on local land rental rates and sales prices, so nonparticipants may have to pay more for land. As a result, other agricultural inputs, such as chemicals, may be substituted for land, reducing net areawide environmental benefits of land retirement.

3) Should an overall budget constraint ever be imposed in the future, overpaying now means that fewer total acres, with associated environmental benefits, can be enrolled.

4) Under very restrictive assumptions, the ordering of program options using governmental and social accounting perspectives would be the same. For this to obtain, the ranking of benefit/cost ratios, $\Sigma SB_i/\Sigma SC_i$, would have to be the same as, for example, the $\Sigma A/\Sigma GP_i$ ratios. This would be true if SB_i were a constant and if SC_i and GP_i were proportionately related.

V. Results from Bidding Models in Literature

One way for the government to increase cost effectiveness would be to estimate individual parcel reservation prices based on productivity/crop yields, crop enterprise systems, and whole farm factors (Micro-Targeting Work Group, 1990; Boggess, 1986). These data could then be used to drive representative farm decision models that estimate, among other parameters, cropland retirement reservation prices. The government could then make "take-it-or-leave it" offers based on estimated reservation prices.[4] However, such estimation is complicated by risk and uncertainty faced by farmers in participation decisions that affect farmers' own estimates of reservation prices (Boggess, 1986), as well as the obvious data costs. Consequently such a procedure is likely to be prohibitively expensive if conducted on all parcels, although it may be feasible for some small subset of parcels meeting certain physical eligibility criteria.

The difficulties associated with ex ante identification of reservation prices provide a rationale for developing mechanisms that induce participants to reveal values that at least approach reservation prices. The economic and public policy analysis literature was reviewed with several questions in mind:

1) Which models of bidding mechanisms appear most similar to the current CRP?

2) Do these models generate results that have potential for reducing total government outlays?

3) Is there any evidence that experiments and experience generate results similar to those predicted by theory?

4) Have past applications in real situations actually saved the government money?

Most of the theoretical and applied literature addressing bidding mechanisms and auctions[5] is derived from the theory of games with incomplete information. There is no lack of reading material: a 1979 bibliography listed nearly 500 titles on quantitative models of competitive bidding alone (Stark and Rothkopf, 1979). Several authors

[4]The existence of the CRP's subnational bidding pools and MARRs suggests that reservation prices have been disaggregated to some extent.

[5]The literature does not make a clear distinction between use of the terms "bidding" and "auctions." We, too, use them interchangeably.

have attempted to categorize bidding models and compare their results (McAfee and Preston, 1987; Milgrom, 1989; several authors in Amihud, 1976; Engelbrecht-Wiggans, 1980, Milgrom and Weber, 1982).

We follow Engelbrecht-Wiggans in classifying mechanisms according to the following components and subcomponents:

1. Players
   a. Number of participants
   b. Characteristics of their utility functions

2. Objects being exchanged
   a. Number
   b. Information about object's value
   c. Distinguishing physical characteristics (if multiple objects being exchanged)
   d. Is the object divisible or indivisible?

3. Payoff function
   a. How award is made to bidder(s)
   b. Price paid
   c. Reservation price (of seller)
   d. Other transfer costs such as information or bid preparation costs

4. Strategies of bidders

The large number of permutations of these characteristics, as well as the unfortunate fact that theoretical results derived for one analyzed bidding mechanism may apply only to a small class of other mechanisms, makes it important that we precisely specify the CRP's own bidding mechanism.

(1) With respect to the above classification scheme, the CRP involves many potential participants whose number is determined by known land eligibility criteria. The utility functions of these participants

may be quite complicated and nonlinear[6]; however, for present purposes we treat them as linear in income.

The government knows in advance how many acres meet the CRP eligibility criteria, but it does not know, because of high information costs, how many landowners control the eligible lands. Unfortunately, auctions with a variable number of players have received considerably less theoretical attention than those with a fixed, known, number of bidders (Engelbrecht-Wiggans, 1980). In some models, the number of players is determined by the bid-taker's reserve price (here the MARR) and an entry fee (here undetermined transaction cost factors) (Milgrom and Weber, 1982).

(2) A fundamental characteristic of the CRP is that multiple objects (different size parcels offered by different owners, some or all of which will be accepted) are being exchanged. Unfortunately, multi-object auctions have received far less attention in the literature than single-object auctions, and the models studied tend to be quite specialized (Weber, 1983). The multiple objects being exchanged can be considered the cropping rights to specified parcels for ten years. Their number is random, but is bounded above by the total number of eligible acres divided by the minimum parcel size. The objects' values are not known with certainty by anyone. They differ both because their physical characteristics are different and because an object's marginal value to a

[6]For example, the CRP reservation price is sensitive to the number of acres bid because of the immobility of certain factors of production such as machinery (Johnson and Clark, 1989).

bidder may vary with parcel acreage. The objects are divisible (number of acres in a parcel) up to a point.

(3) The payoff function is to pay each of the successful bidders the value of their bids. The bidders have minimum reservation prices that represent foregone opportunities, and the bid-taker has a maximum payment level (the MARR).

(4) A bidding strategy is a decision rule that specifies how a player will use any information observed to determine the actual bid. In most multiple-bidder models, Nash equilibrium strategies are sought in which each player maximizes expected utility, given the strategies used by other players. Such behavior does not need to be postulated for the current CRP, however, because there is no binding constraint (other than the 25% county maximum in certain rare circumstances). We show in a later section how the CRP might be adapted to a strategic game, following imposition of binding constraints.

Although the CRP's characteristics do not conform exactly to any model found in the literature, it approximates certain multiple-object sealed bid forms, such as U.S Treasury Bill auctions (Weber, 1983). Two differences are that the number of objects (the dollar value of the issue) being exchanged in T-bill auctions is fixed, and most multiple-object auctions allow players to bid on more than one object.

These and other differences make it difficult to apply existing models to the CRP cost-effectiveness problem. Auction models are seldom analyzed for their robustness, and many require certain parameters or probability distributions to be determined empirically (Engelbrecht-Wiggans, 1980). Because theoretical results may not be robust to small deviations or inaccuracies in determining parameters, applying derived results to the CRP must be done with caution. For example, in a single object auction, the value of the winning bid converges asymptotically to the true value of the object as the number of bidders becomes sufficiently large (Wilson, 1977). However, share auctions (in which bids are for a fractional share of an object) such as that for T-bills (and for the CRP) can lead to less revenue (greater outlays) than unit auctions because they are subject to manipulation by bidders. The bid-taker (the government) may receive no benefit from competition as the number of bidders increases (Wilson, 1979).

In addition, single-object forms tend to have more easily defined solution concepts. Some forms of multiple-object auctions (especially when bidders may submit bids for more than one object) may not have any Nash equilibria, or the Nash equilibria may not be unique. In such cases, alternative solution concepts must be used (Palfrey, 1980). With multi-object auctions in which there are qualitative differences among the objects, it is not even clear that there is a definable algorithm for an optimal solution (Vickrey, 1976).

In single object auction models, a standard result is that closed and open forms yield identical expected outcomes (revenues or outlays) (Milgrom and Weber, 1982). When multiple objects, such as CRP land parcels, are auctioned, the situation is more complicated. Multiple object open bid auctions typically announce winners for each object during the bidding period. With the CRP, the government announces accepted bids only after the round closes. Potential bidders observe a sequence of bids whose range may bracket their own reservation prices. Information about previously submitted bids may affect subsequent bids. Early bidders might initially understate true reservation prices in hopes of lowering others' bids and then resubmit a higher level as the bidding period draws to a close. Such deception strategies are discussed by Hausch (1986).

The existence of the MARR also makes it difficult to apply results from other models to the CRP. In single object auctions, when the bid-taker (the government) announces a maximum acceptable bid, expected outlays are reduced (Milgrom and Weber, 1982). Under some conditions, however, any decrease in the expected number of bidders increases the bid-taker's total payments more than the decrease in total payments due to the lower maximum acceptable bid (Engelbrecht-Wiggans, 1987).

The CRP's multiple rounds of bidding may also complicate the analysis. If there are positive opportunity costs to the bid-taker for waiting for additional bids (either from those previously rejected or from new bidders), then it may be better for the bid taker to accept any bid that is lower than some specified amount and to reject all others. The problem for the bid-taker is to specify the best stopping rule, or cut-off level. This problem becomes more complicated if the bidding distribution changes over time in response to dynamic aspects of the economy (McCall, 1976).

Has competition saved the government money (or increased its revenues)? Empirical results are sketchy, but appear mixed. The question, "Compared to what?" makes this type of analysis difficult. Moody and Kruvant (1990) concluded that for Outer Continental Shelf leases, a change in policy that reduced the number of bids per tract (less competition) lowered government revenues. Studies of defense procurement, however, show mixed results in terms of government savings (Anton and Yao, 1990; Yuspeh, 1976; Vartabedian, 1990).

VI. Characterization of a CRP-like Bidding Mechanism

In this section, we present a model of a CRP-like policy instrument that incorporates a competitive bidding mechanism. The model faithfully captures the CRP's essential features: landowners voluntarily submit bids to receive annual payments for retiring eligible parcels and asymmetry exists between the government's and landowners' knowledge of individual reservation prices.

To facilitate analysis, the land retirement policy instrument posited abstracts somewhat from the real CRP. The simplifying assumptions used (some of which are relaxed later) are as follows:

1) The numbers of eligible acres and the smaller number of acres to be enrolled are exogenously determined by the government prior to bidding.

2) Social benefits from land retirement are constant among all eligible acres and society derives constant marginal utility from land retirement, within the range of eligible acres. Social costs do not enter directly into the government's problem. Thus, the government is concerned only about achieving its acreage goal for the least expenditure.

3) There is but one round of bidding.

4) Each owner of eligible land has exactly one acre of land to bid in to the program. The total acreage for which bids are submitted always equals the number of eligible acres.

5) Transactions costs from bidding are zero; therefore, all eligible landowners submit bids.

6) Landowners solve identical maximization problems with utility functions that are single-valued over income. The form of the landowners' problem is known by the government.

7) Both landowners and the government are risk neutral.

8) Fixed production costs and nonmarginal effects are ignored, so that private opportunity costs of land retirement are not affected by the proportion of a farm's total area represented in a bid or by the total acres enrolled within a local jurisdiction.

9) All landowners know with certainty their own and only their own reservation price, but believes that every other bidder's reservation price is drawn independently from the same underlying distribution.

10) The government does not know any individual reservation price, but has the same belief about their underlying distribution as the landowners.

11) All accepted bids are paid at their respective dollar/acre values.

The model requires that the government agency solve an optimization problem, given its acreage goal and land eligibility criterion. (With the actual CRP, Congress established national acreage and other broad policy parameters to be implemented by local agencies that, so far, have not had direct budget constraints.) The problem could be specified alternatively as expenditure minimization subject to an acreage enrollment constraint, or as enrollment maximization, subject to a budget constraint. We choose to specify the expenditure minimization problem for two reasons. One is that the current CRP has national acreage enrollment goals but no budget constraint. However, this may not last; reducing federal budget outlays is a perennial policy objective. The other reason is that this specification is more amenable to comparison with existing bidding models that focus on expected revenues (here outlays). Specifying the government's problem as one of acreage maximization would yield symmetric results.

After receiving a set of bids, the government mechanically follows previously established and announced bid selection rules. Its problem can be expressed according to ex ante expectations of landowner response to those rules. Thus, the government's problem is:

$$\underset{X}{\text{Min}} \quad \text{Expected Outlays} = \sum_{i}^{I} E[B\hat{I}D_i]X_i \tag{1}$$

subject to

$$\sum_{i}^{I} X_i = A \tag{2}$$

where

i = 1...I parcels of eligible land. There is one parcel per agent.

$E[B\hat{I}D_i]$ = expected equilibrium bid of agent i, given the bidding mechanism established by the government (discussed below).

X_i = the government's decision rule for bid acceptance. $X_i = 1$ when $B\hat{I}D_i$ is accepted, and $X_i = 0$ when $B\hat{I}D_i$ is rejected.

A = the government's acreage enrollment goal.

Equation (2) is simply an equality constraint. If ΣX_i could be less than A, the government could always minimize outlays by retiring only the least expensive parcel. On the other hand, if landowners know that more than A acres may be accepted, then A would not serve as a binding constraint to stimulate competitive bidding. In this specification, the local agency's ability to optimize before bids are received is limited to its discrete choice about the bidding procedure to be followed and announced to landowners. Operationally, the agency merely accepts received bids in increasing dollars/acre order until A is reached and rejects the rest.

For their part, farmers seek to maximize expected utility, given that the probability of any dollar/acre bid being accepted is determined by the announced bidding parameters. Utility U_i is assumed to be concave and continuously differentiable. Each landowner's problem is:

$$\max_{BID_i} E[U_i] =$$

$$U(BID_i)*Pr[BID_i \text{ accepted}] + U(RP_i)*Pr[BID_i \text{ rejected}] \qquad (3)$$

where

$$Pr[BID_i \text{ accepted}] = 1 - Pr[BID_i \text{ rejected}] = Pr[X_i = 1 \mid BID_i]$$

In the Appendix, we derive results for the landowner's problem based on similar models in the bidding literature (Harris and Raviv, 1981; McAfee and McMillan, 1987; and Holt, 1980). These results give rise to several insights from this simple model.

First, a Nash equilibrium bidding strategy, initially only assumed to occur, does indeed result from each landowner solving her respective problem. Define $B\hat{I}D_i \equiv BID(RP_i)$ as the symmetric Nash equilibrium bid. For each participant, $B\hat{I}D_i$ maximizes expected utility when her true reservation price is RP_i, given that each other bidder is using the same strategy. No bidder has an incentive to deviate from this strategy, given that all others follow it.

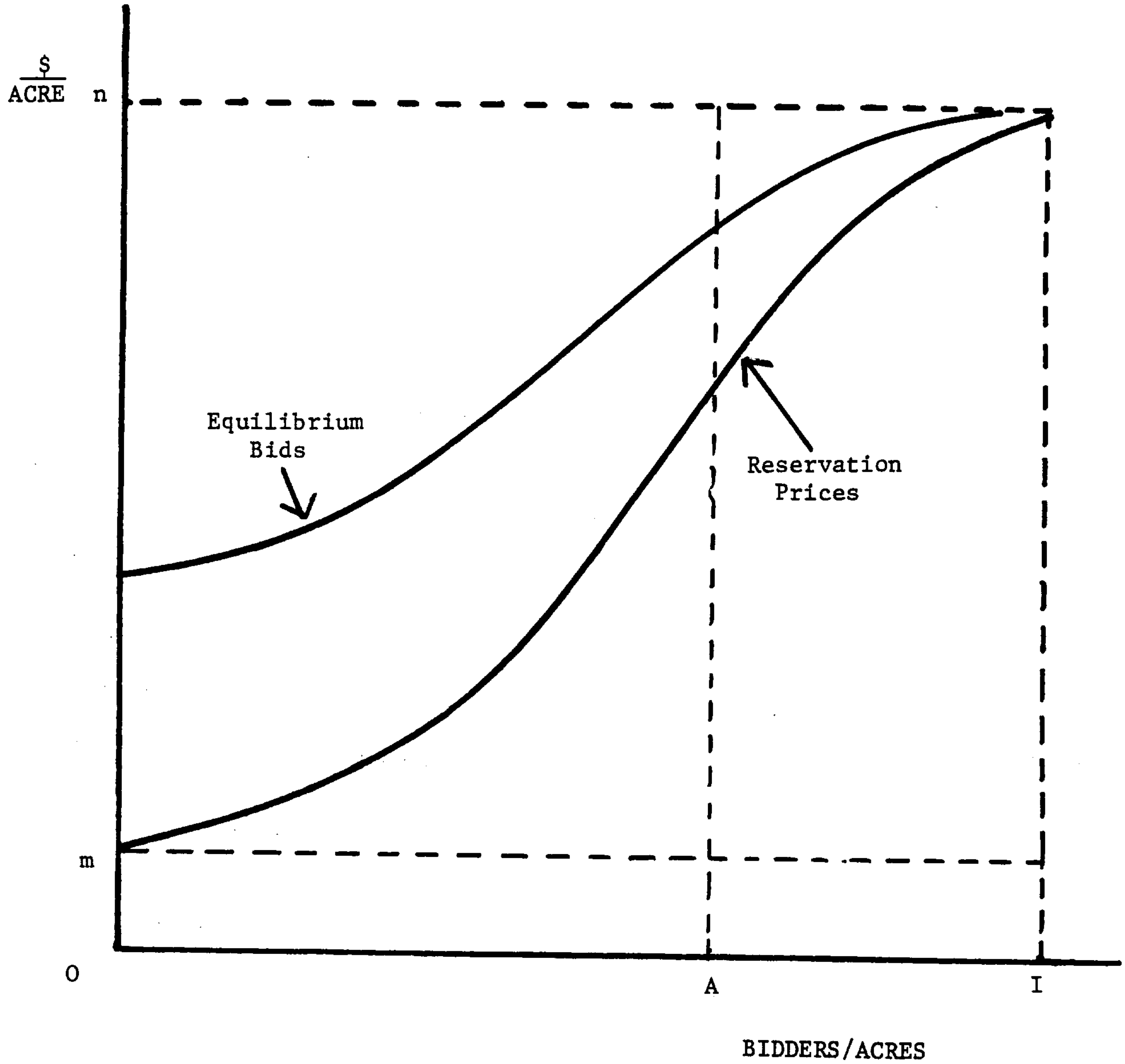
Second, under these conditions, equilibrium bids <u>strictly</u> exceed associated reservation prices along a range in which landowners believe there is positive probability that all RP_i are located. Thus, in this model with competition, the government can not avoid paying something more than true reservation prices to retire land. In particular, the government's expected total outlays (before bids are received) are A * $E[RP_{A+1}]$, where the term in brackets is the reservation price associated with the lowest rejected bid.

Third, the values for I and A (while exogenously determined) affect equilibrium bidding strategies and, hence, expected government payments per acre. The probability that landowners assign to bid acceptance decreases as competition (I - A) increases, all else equal (including the underlying distribution of reservation prices). This is because, with more bids to be submitted over the same reservation price distribution, there is a smaller expected dollar/acre interval between the reservation price associated with the Ath ordered bid (accepted) and the A+1th bid (rejected). In the next section, we discuss endogenizing I and A.

Fourth, bidders owning parcels that have relatively high reservation prices are effectively forced to bid at levels not much greater than their reservation prices. That is, if a reservation price is close to the high end of the distribution, the associated equilibrium bid becomes squeezed close to that reservation price.

In the context of the hypothetical relationship between ordered reservation prices and the offer curve shown in Figure 1, the modeled relationship between ordered reservation prices and the offer curve from equilibrium bids looks something like that shown in Figure 3. The difference between bids and their respective ordered reservation prices is relatively large when reservation prices approach their lower bound (m), while bids converge to reservation prices at their upper bound (n). These results indicate that a model with competitive bidding does increase cost effectiveness; however, it does not result in accepted bids paid at their reservation prices.

Figure 3: Hypothetical Relationship Between Ordered Equilibrium Bids and Reservation Prices When Government Sets an Acreage Constraint



VII. Variations on the Basic Model

In this section, we discuss the implications of relaxing or varying several of the conditions initially assumed for the above model. While formal derivations are beyond the scope of the present paper, we apply results from similar models in the literature to conjecture on the implications for the basic model. The order in which assumptions are discussed is arbitrary; unless stated otherwise, the effects of relaxing different assumptions are independent of each other.

Relaxing the assumption that <u>I and A are both exogenously chosen</u> would give the government choice variables to affect bidding behavior. As shown in the Appendix, the equilibrium bidding strategy is affected by I - A. The general result that intensifying competition induces equilibrium bids to converge toward reservation prices is found in many auction models (Wilson, 1977).

Suppose that, under some alternative definition of parcel eligibility, there are H eligible parcels, where H > I. The number of parcels to be enrolled, A, is held constant to meet mandated national acreage enrollment goals. Then expected total government outlays for enrolling A acres are less than under the original eligibility definition, all else equal (As discussed below, all else may not be equal.). Alternatively, the number of eligible acres could be held constant at I, while a smaller number of acres to be accepted is announced, generating a lower offer curve. This, of course, would lower total social benefits since fewer acres are retired.

The government's problem changes substantially if the assumption of <u>constant social benefits from land retirement</u> (all eligible parcels are equally desirable) is relaxed. Marginal social benefits from land retirement may vary because of physical heterogeneity or because of declining marginal utility for acreage retired. The current CRP does not distinguish among eligible parcels' individual social benefits in bid selection or payment amount, despite evidence that the various environmental services resulting from land retirement are function of parcels' heterogenous physical characteristics (Kozloff, 1990; Kozloff and Taff, 1990). Some of these environmental services, such as wildlife habitat expansion and water quality improvement, may be subject to declining marginal utility as retired acreage increases.

Regardless of whether marginal social benefits decline because of declining marginal utility or physical heterogeneity, the government's earlier problem may be respecified, for example, as minimizing total outlays subject to achieving some level of social benefits ($\Sigma X_i * SB_i$). If eligible parcels are relatively homogeneous, increasing the number of eligible parcels/bidders (I) will tend to decrease government payments without affecting total social benefits realized from retiring A acres. If, however, declining marginal benefits are due to physical heterogeneity, then relaxing the eligibility criterion also reduces the average social benefit from accepted bids.

Under these conditions and assuming the government knows SB_i, it faces a trade-off in defining parcel eligibility: Increasing I tends to reduce both government payments and social benefits from accepted bids. While the potential sensitivity of total social benefits to alternative land eligibility criteria was debated during the CRP's statutory development, this trade-off arises only because of the competitive nature of the bidding mechanism.

The assumption that bids are paid at their face value may also be relaxed since the government could adopt and announce some other award procedure for paying accepted bids. The above model is an example of what is called a "discriminating" auction: accepted bids are paid at their respective dollar/acre levels. In a "competitive" auction, on the other hand, all bids are paid at the lowest rejected bid. In a discriminating auction, therefore, each bidder faces uncertainty about bid acceptance, but not about payment if the bid is accepted. In a competitive auction, however, the bidder faces uncertainty about both bid acceptance and ultimate payment.

While it might seem that the government's expected total outlays would be greater under competitive auction models, they are the same when bidders are risk neutral as assumed above (Weber, 1983; Harris and Raviv, 1981; Smith, 1966; Holt, 1980). Intuitively, incentives for bidder behavior are different under the two auction types. In a competitive auction, a bidder knows that bidding higher than his reservation price reduces the probability that the bid will be accepted, even though the price at which the contract is written (the lowest rejected bid) is unchanged. In this situation, the Nash equilibrium strategy is $BID_i = RP_i$. Thus, the mean bid accepted is lower than with the discriminating auction, even though total outlays are the same.

This result changes when the risk neutrality assumption is relaxed. When bidders are assumed to be risk averse, competitive auction models yield lower expected outlays than discriminating models (Weber; Harris and Raviv).

Relaxing the single bidding round assumption would cause the one period problems of farmers and the government modeled earlier to both become adaptive control problems. As Reichelderfer (1986) notes:

> The observed decisions by each [bidder], in a given time period, will be used as a basis for the succeeding time period's critical decisions. As the government and farmers gain better and better knowledge of each other's behavior over time, one might expect a cobweb configuration of decisionmaking to converge on an optimal level of CRP participation that satisfies the objectives of each set of decisionmakers, as constrained by the other's agenda. This, however, presumes that objectives do not vary over time and that observed decisions are accurate indicators of behavioral motivation.

The bidders' problem now becomes one of maximizing expected utility associated with the discounted present value of a stream of income from either government payments or continued cropping at reservation prices. Because they can observe bids submitted in previous rounds, bidders can update their beliefs about the distribution of other bidders' reservation prices, which in turn allows them to adjust probabilities over bid acceptance. At the same time, the payoff from bid rejection is no longer simply measured by reservation price but rather by the expected present value of reservation price for one or more periods plus an accepted bid in some subsequent period. By bidding high, bidders stand to gain over the entire life of the contract, while, by bidding low, they increase the probability of near term bid acceptance. The time stream of payoffs from submitting an accepted bid in a given round (10 years under the current CRP) is longer than the stream from bid rejection, since a rejected bidder can bid in a subsequent round. Discounting obviously plays an important role in the formation of optimal bids.

The government also solves a more complicated problem. If the announced acreage enrollment goal in any given round is relatively high, the government locks itself into a ten year stream of payments on relatively high bid prices. If the acreage goal is set low, the government foregoes social benefits from not retiring certain parcels, at least until the next bidding round. However, waiting to retire a parcel in a subsequent round lowers the present value of government outlays. Thus, updating information about reservation prices from observing previously submitted bids may help the government establish bidding parameters in subsequent rounds.

VIII. Policy Implications for the Current CRP

The previous discussion has been based on a land retirement program that does not currently exist. In implementing it, the government seeks to solve an optimization problem. While the discussion may be applicable to future land management programs, such as the wetland reserve program contemplated in the 1990 federal farm bill, it doesn't necessarily apply to modification of an existing program like the CRP.

As of this writing (October, 1990), the original CRP has been extended with expanded land eligibility provisions for additional acreage enrollment. In this section, we adapt previous findings to suggest some improvements over the CRP's current bidding mechanism. Recall that farmers in each pool know their respective MARRs from observing previous rounds' outcomes; there are no budget or acreage constraints (except in those counties where the 25% county acreage limit is binding, in which case there is no more CRP entry); and there are multiple bidding periods whose remaining number is not known to potential bidders. Because landowners expect continuation of the current bidding mechanism and possess the above information, it is more difficult to make recommendations that fulfill both cost effectiveness and political feasibility criteria than it would be to make such recommendations for a new program. For example, future participants may so resent modification of the current bidding mechanism that they refuse to bid.

In making these recommendations, potential savings in government outlays should not be overstated. Potential savings are those measured by the difference in true reservation price and paying everyone at the MARR. This potential is analogous to the difference in outlays shown in Figure 1. Only some fraction of these savings are achievable by most bidding schemes. Too, the present CRP is already achieving a (small) portion of these savings, as discussed in Section II. Finally, only a portion of the estimated savings will actually be realized, given the necessary compromises made in program administration and the certain deviation between modeled and actual behavior of landowners.

These caveats notwithstanding, changes in the CRP's current bidding mechanism should be directed toward increasing competition: Potential bidders must be given information that causes them to assign a positive probability to bid rejection that increases as the bid's per acre value increases. Limiting either expenditures or acreage within a given jurisdiction and bidding round, coupled with enrolling bids in order of lowest to highest per acre value (as is nominally true in the current program), may achieve this reassignment of probabilities. This general prescription appears robust even if several simplifying assumptions are relaxed.

While the specifics of an improved bidding mechanism are yet to be determined, it may have some of the following features. In the current CRP, not all eligible bidders are observed to actually bid in a given round, for reasons such as lack of information, the opportunity to increase expected utility through Bayesian learning, high transactions costs, or certain knowledge that reservation price exceeds the bid cap. This complicates the government's problem relative to our model. To generate competitive behavior, the government wants the number of bidders to exceed the acreage goal, but if that is set too low, environmental objectives may not be achieved.

The government can influence the number of actual bidders to some extent. Public information provided prior to bidding may change the perception of opportunity costs of participating (Baron). For example, expectation of lower crop prices (influenced by other government programs) may increase the number of bidders and decrease bid levels, because reservation prices would be lower.

With several remaining rounds of bidding, acreage enrollments could be set to induce competition within a given bidding round. Then successive bidding rounds could be held until a long term acreage goal is met. If the optimization problem facing the government is the dual of the one presented in Section VI, then inducing competition by limiting the budget would be analogous to this feature. Here, the government would announce that bids would be accepted from lowest reservation price until an announced budget constraint within that round is reached.

While the discriminating auction model more closely resembles the manner in which the CRP was intended to operate than does the competitive auction (which is more specific than the rubric "competitive bidding"), the outcome of the current process more resembles a competitive auction. That is, most payments made to successful bidders approximate the fixed MARR. This suggests that the uniform payments (at the level of the lowest rejected bid) of a competitive auction may have the advantage of perceived equal treatment across landowners. Implementing the CRP as a competitive auction in this sense may improve program cost effectiveness with relatively little sacrifice of public acceptability.

Finally, in conjunction with generating competitive behavior, the MARRs could be abolished. While the MARRs now constrain the upper bound at which bids are paid, they would not be binding if bidding were truly competitive. Without the MARRs, the current bid pool regions would have no purpose. It must be recognized, however, that the MARRs and bid pools also serve to spread land retirements among regions throughout the country with disparate opportunity costs of retirement by imposing regional ceilings on maximum acceptable bids. There may be some social purpose (other than income redistribution) for limiting the competition for land retirements to relatively homogeneous regions. If so, this could still be achieved by limiting bid submission and selection to landowners within the jurisdiction of the county ASCS office.

IX. Research Directions

Under certain conditions, appropriate changes in the current CRP bidding mechanism offer potentially significant savings in government outlays. Before any such changes are implemented, more research is advisable. Theoretically optimal behavior is rarely observed, either in experimental situations or in actual program implementation. Furthermore, American farmers traditionally demonstrate great resourcefulness in "farming the programs," finding ways to maximize private gains in the face of often complex and restrictive program rules. In solving their individual optimization problems, farmers may unintentionally subvert the public purposes associated with the programs. Thus, there is a wide gap between the ex ante cost effectiveness of program provisions and their ex post realization.

For these reasons, future research on bidding mechanisms for land retirement should employ both experimental and pilot study analyses of the most theoretically promising mechanisms. As Smith (1976) notes, "Perhaps the most important ultimate value [of experimental analysis] is to provide rigorous testing of our ability to model elementary behavior before confronting such models with field data." Experimental approaches should ideally draw from the population of potential participants for sample study groups. Experiments can provide relatively inexpensive short term answers to such questions as:

(1) Are the models sufficiently straightforward that subjects are able to make consistent decisions based on underlying behavioral incentives?

(2) Are the behavioral incentives predicted by the models reasonable reflections of how program participants behave when faced with simulated choices?

(3) Do the models appear robust with respect to minor deviations in parameters?

While experiments may prove valuable in addressing such questions, they are still a step removed from real landowner responses to real program offerings. Bidders may respond differently to economic transactions of magnitudes comparable to those experienced with the CRP than those typically used in experimental situations. In addition, actual program implementation is rarely as controlled as the protocol of an experiment. For these reasons, pilot studies of those models that appear most promising from an experimental perspective would be useful to address questions of administrative feasibility as well as participant responses to derive more realistic estimates of program cost effectiveness. In addition, pilot studies would allow estimation of transaction costs associated with alternative schemes. Finally, such studies would indicate political and psychological acceptability of the government's desired outcome of filling bids at heterogeneous dollar per acre values.

Regardless of the choice of particular research agenda, the large budget commitment associated with present land retirement programs and the demonstrated potential gains from competitive bidding both suggest that more cost-effectiveness research be conducted before new programs are initiated.

APPENDIX

In Section VII, we present a model in which total government outlays are the sum of a set of Nash equilibrium bids $\hat{BID}_i$. Here, we derive an expression for $\hat{BID}_i$. To simplify notation, let $BID_i = b_i$ and, to reflect that reservation prices are independent random variables, let $RP_i = \theta_i$, so $\hat{BID}_i = b(\theta_i)$. We restate or assume the following conditions:

1. There are I eligible parcels.
2. The government wants to retire A parcels, where $A < I$.
3. a) Each landowner $i = 1, \ldots I$ has one eligible parcel whose reservation price θ_i is known with certainty by i but not by other landowners.

   b) Landowners believe that rival's reservation prices are drawn from the same distribution: p.d.f. $g(\cdot)$ and c.d.f. $G(\cdot)$. Assume $g(\cdot) > 0$ on some finite interval (m, n).
4. Each landowner submits bid b_i and believes that each of the $I - 1$ rivals uses a differentiable and strictly increasing bidding strategy $b_j = b(\theta_j)$ for $\theta_j \epsilon (m, n)$ $j \neq i$.
5. Each landowner is risk neutral and has the same twice differentiable utility function $U(\cdot)$, where $U(\cdot)$ is concave and $U(0) = 0$. Further restrict U to the case of $U(x) = x$; i.e., U is the identity.
6. Define $\pi(\cdot)$ as the inverse of the bidding strategy $b(\cdot)$, so that $\pi[b(\theta_j)] = \theta_j$.
7. Reservation prices for the I eligible parcels are indexed so that $\theta_1 \leq \theta_2 \leq \ldots \leq \theta_I$. Define $\theta_{(1)} \ldots \theta_{(I)}$ to be the order statistics of $\theta_1 \ldots \theta_I$.

8. Define $b(\theta_A) = b_A$ as the Ath smallest bid among the I-1 rival bidders.

From the monotonicity of $b(\cdot)$, the smallest rejected rival bid is b_{A+1}, and i's bid is accepted if $b_i < b(\theta_{A+1})$. Then the probability that b_i will be accepted is equivalent to the probability that $\pi(b_i)$ is less than $\theta_{(A+1)}$ (the A+1th order statistic from the I-1 reservation prices of the rival bidders):

$$\Pr[\text{accept } b_i] = \Pr[b_i < b_{A+1}] \tag{A1}$$

$$= \Pr[\pi(b_i) < \theta_{A+1}] = 1-F[\pi(b_i)] \tag{A2}$$

where $F[\cdot]$ is an increasing function of b_i and denotes the cumulative distribution representing each landowner's prior beliefs about $\theta_{(A+1)}$.[9] The corresponding p.d.f. is $f(\cdot)$.

The ith landowner's maximized expected utility can now be expressed by substituting (A2) into equation (3), the original landowner objective function:

$$\text{Max } E[U] = U(b_i)(1-F[\pi(b_i)]) + U(\theta_i)F[\pi(b_i)] \tag{A3}$$

The first order necessary condition for an optimal bid is

$$U'(b_i)(1-F[\pi(b_i)]) - [U(b_i) - U(\theta_i)]f[\pi(b_i)]\pi'(b_i) = 0 \tag{A4}$$

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[9] From the properties of order statistics, if $F[\cdot]$ is the c.d.f. of $\theta_{(A+1)}$ and x is the value of the reservation price of the ith parcel known by the ith bidder, then

$$F(x) = \Pr[\theta_{(A+1)} \le x]$$

$$= \Pr[\text{at least A+1 of the } \theta_i \text{ are less than or equal to x}]$$

$$= \sum_{i=A}^{I} \left(\frac{I!}{(I-A)!A!}\right) G(x)^i[1-G(x)]^{I-i}$$

for all $\theta_i \epsilon (m, n)$ (David, 1970, p. 7).

In a symmetric Nash equilibrium, all bidders use the same strategy. Therefore, the inverse strategy function will be the same $\theta_i = \pi(b_i)$ for all $i = 1 \ldots I$. Replacing $\pi(b_i)$ in (A4) with θ_i gives

$$U'(b_i)b'(\theta_i)[1-F(\theta_i)] - [U(b_i) - U(\theta_i)]f(\theta_i) = 0 \tag{A5}$$

because $b'(\theta_i) = \dfrac{1}{\pi'(b(\theta_i))}$

Because of how U is defined,[10] (A5) can be rewritten as:

$$b'(\theta_i)[1-F(\theta_i)] - [b(\theta_i) - \theta_i]f(\theta_i) = 0 \tag{A6}$$

or

$$\frac{d}{d\theta_i}[(1-F(\theta_i))b(\theta_i)] = -\theta_i f(\theta_i) \tag{A7}$$

Solving for the optimal bid gives the Nash equilibrium bidding strategies as a function of θ_i:

$$b(\theta_i) = \frac{1}{1-F(\theta_i)} \left\{ \int_{\theta_i}^{n} xf(x)dx \right\} \tag{A8}$$

Let $u = -x$, $dv = -f(x)dx$, $du = -dx$, and $v = 1 - F(x)$. Integrating the right side of (A8) by parts, $\int udv = uv - \int vdu$,

$$b(\theta_i) = \frac{1}{1-F(\theta_i)} \left[-x(1-F(x)) \Big|_{\theta_i}^{n} + \int_{\theta_i}^{n} (1-F(x))dx \right]$$

$$= \theta_i + \int_{\theta_i}^{n} (1-F(x))dx \tag{A9}$$

Therefore, $b(\theta_i) > \theta_i$ and $\lim_{\theta_i \to n} b(\theta_i) = n$. Since $b(\theta_i)$ is strictly increasing between m and n and is bounded by n, it is a Nash equilibrium.

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[10] See Holt (1980) for an alternative derivation that retains U.

The right side of (A8) is the payoff to i when equilibrium bids are based on reservation price θ_i. Recall that f(•) is defined as the p.d.f. of $\theta_{A+1} \leq \theta_i$. Then by the definition of the expectation of a conditional value,

$$b(\theta_i) = E[\theta_{A+1} \mid \theta_i < \theta_{A+1}] \tag{A10}$$

(A10) can be interpreted to say that the equilibrium bidding strategy is equal to the expected value of the reservation price associated with the minimum rejected bid, conditional on $\theta_{A+1} > \theta_i$. Because $\theta_{A+1} > \theta_i$ implies $b(\theta_{A+1}) > b(\theta_i)$, i's payoff, evaluated at i's equilibrium bid, is equal to the expected value of the lowest rejected reservation price, given that i's bid is accepted (Holt, 1980).

Equation (A10) also gives rise to the equivalence in total expected government outlays between discriminating and competitive auction models as discussed in Section VII. Expected outlays under both models are $A*E[\theta_{(A+1)}]$ (Weber, 1983; Harris and Raviv, 1981).

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