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Bidding Games for Valuation of Aesthetic Environmental Improvements[1]

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An empirical case study of the benefits of abatement of aesthetic environmental damage associated with the Four Corners power plant and Navajo mine using the bidding game technique is presented. Bidding games were carefully designed to avoid the potential problems inherent in that technique. The results indicate the existence of substantial benefits from abatement of this aesthetic environmental damage. Aggregate bid curves, marginal bid curves, and estimates of the income elasticity of bid are presented. The effectiveness of the bidding game technique is discussed.

It has proved a difficult and often forbidding task to ascribe economic values to environmental improvements. Yet, rational and informed social decision making requires, among other things, a consideration of the economic costs and benefits of environmental improvements. The difficulties in economic evaluation are compounded in the case of environmental improvements of an aesthetic nature. This article discusses the problems inherent in the valuation of aesthetic environmental improvements and presents a case study in which bidding games were used as the valuation technique.

THE THEORY

Aesthetic damage to an outdoor environment, to the extent that it diminishes the utility of some individuals, is a discommodity and its abatement is a commodity. Abatement of this kind of external diseconomy is both a nonmarket good, since it is nonexclusive, and a public good in the sense of Davis and Whinston [6], since it is inexhaustible at least over a very substantial range. That is, additional consumers of this kind of aesthetic environmental improvement can be added without diminishing the visibility or scenic beauty available to each (at least, until crowding occurs). Additional users can be added at near zero marginal cost, over a substantial range.

Bradford [2] has presented a theoretical framework for the valuation of public goods. Traditional demand curves are inappropriate for the analysis of demand for

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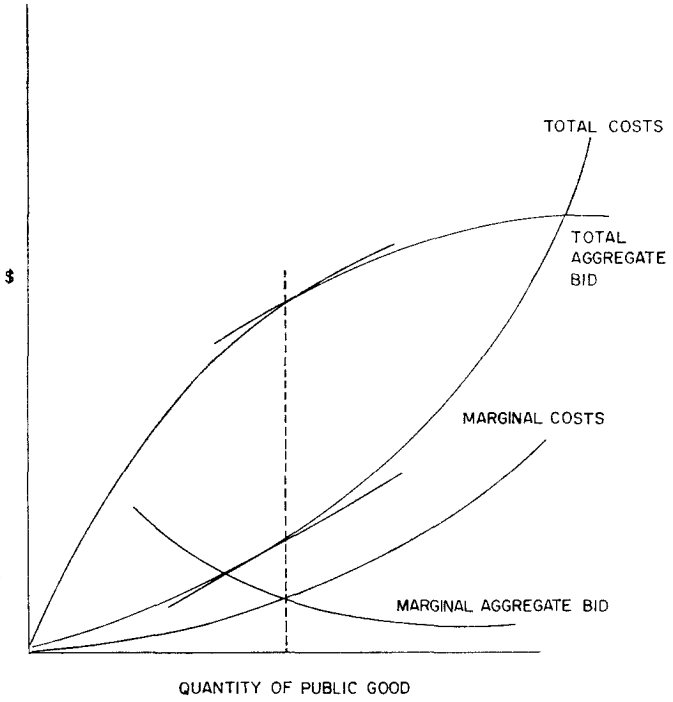

FIG. 1. Collective optimization of the quantity of public good provided.

public goods, since the situation is not one of individuals responding to a parametric price per unit by choosing an appropriate number of units. Rather, the individual directly arrives at the total value to himself of various given packages. In the case of a public good, the individual is unable to exercise any choice over the quantity provided him, except as a member of the collective which makes a collective choice. Further, the nature of a public good such as aesthetic environmental improvements is such that increases in the quantity provided are not purely quantitative increases, but are more in the nature of improvements in quality. Thus, the individual values alternative packages of a public good, which may differ in quantity and quality.

Bradford proposes the concept of an aggregate bid curve for public goods. Individual bid curves are simply indifference curves passing through a given initial state, with the numeraire good (which can be dollars) on the vertical axis and the public good on the horizontal axis.[2] The aggregate bid curve is the algebraic (or vertical, in diagrammatic analyses) summation of individual bids over the relevant population.

The aggregate bid curve is an aggregate benefit curve, as it measures precisely what an accurate benefit-cost analysis of provision of a public good would measure as benefits. Using the approach of methodological collectivism, efficiency in the provision of a public good can be achieved by maximizing the excess of aggregate bid over total cost, or equating the first derivative of aggregate bid (i.e., marginal bid)

[2] If different packages of a public good represented continuous quantitative increases, the individual bid curve would be smooth and would exhibit decreasing marginal utility of increasing quantities of the public good. However, Bradford's concept of different packages differing in quantity and quality logically implies that individual bid curves need be neither smooth nor of continually decreasing slope. Bradford insists that, *a priori*, nothing can be said about the slope of the "demand," or marginal bid curve, for a public good of this nature.

with the marginal cost of provision.[3] Figure 1 shows the efficient level of provision of a public good.[4]

THE BIDDING GAME TECHNIQUE

It is possible to conceive of a number of techniques for estimating the aggregate bid curve for environmental improvements. Two general classes of techniques, direct costing techniques and revealed demand techniques, have been suggested in the literature and applied in empirical studies. Each of these has its difficulties, especially when adapted for valuation of aesthetic environmental improvements. These techniques will be briefly discussed below. Then, a third type of technique, bidding games, will be proposed. Bidding game techniques are themselves not without difficulties, but we will argue that there may be applications for which they are the preferable or even the only feasible method for empirical studies. Methods of maximizing the reliability of bidding games will be discussed and an empirical study using bidding games will be presented.

Direct costing methods. Implicit in the concept of a "marginal value of damage avoided by abatement" curve, as proposed by Kneese and Bower [12], is the idea of estimating the benefits of abatement of environmental damage by directly estimating the costs attributable to that damage. Several workers have made progress along these lines. For example, Lave and Seskin [13] have had some success in relating the costs of impairment of human health to levels of air pollution. If all relevant costs of a particular incidence of environmental damage can be identified, evaluated and summed, a curve relating the value of damage avoided to levels of environmental improvements can be fitted. The first derivative of this curve is the "M.V.D.A." curve of Kneese and Bower [12].

These costing techniques are theoretically sound and may often be feasible in practice. However, difficulties may be introduced by the unavailability of information and the pricing and accounting problems inherent in this type of analysis. These techniques will have limited application in valuation of aesthetic environmental improvements, since the costs of aesthetic damages may seldom be directly reflected in the market.

Revealed demand techniques. Revealed demand techniques have been widely used for estimation of the demand for outdoor recreation, often a nonmarket good.[5] A number of applications to valuation of the benefits of air pollution abatement have been made [1, 11, 14, 16, 18]. The principle is as follows. The benefits of provision of a nonmarket good are inferred from the revealed demand for some suitable proxy. In the case of air pollution abatement, the revealed demand for residential land is related by regression analysis to air pollution concentrations. In metropolitan areas, it is possible to obtain information on the concentration of specific air pollutants in different parts of the city. If all other variables relevant to the valuation of urban residential land can be identified[6] and measured, it ought to be possible to determine by

[3] In the approach of methodological individualism, Pareto-efficiency is still not achieved since the price to the individual cannot equal the marginal cost to the individual (which is zero) and allow collection of sufficient funds to cover the total cost of provision.

[4] In Fig. 1, the aggregate and marginal bid curves are drawn as smooth curves consistent with diminishing marginal utility. As pointed out in footnote 2, this need not be even the typical case.

[5] See [4].

[6] Some appropriate variables are size and value of structures on the land, distance from places where services and employment opportunities are concentrated, proportion of park land and open space in the neighborhood, density of population, proportion of various racial and ethnic minorities in the immediate vicinity, and the incidence of violent crimes.

regression analysis the extent to which air pollution concentrations affect observed land values. In this way, a proxy measure of the benefits of air pollution abatement is obtained.

There are a number of difficulties with this type of analysis. Since the value ascribed to air pollution control is derived directly from the regression coefficient of the pollution concentration variable, accurate results require perfect and complete specification of the regression equation. In an interesting recent study, Wieand [17] claims that when such regression models are completely specified, the regression coefficient of the pollution concentration variable may not be significantly different from zero. Another difficulty, researchers in the field agree, lies in interpretation of the results. Are all of the benefits of air pollution abatement captured in residential land values? Most think not. For our purposes, the other side of that coin is of interest: Surely some benefits in addition to the aesthetic benefits are captured. Which additional benefits?

In the case study reported below, the geographical area affected by environmental damage includes urban areas, but also rural and agricultural areas, and substantial areas of Indian reservation and National Park, Monument, and Forest lands (which are typically not exchanged in the market). Thus, those revealed demand techniques currently available would seem to be inapplicable to the situation faced in our study.

Bidding games. In analysis of the demand for outdoor recreation, Davis [7] pioneered in the use of bidding games. During personal interviews, the enumerator follows on iterative questioning procedure to elicit responses which enable the fitting of a demand curve for the services offered by a recreation area. Respondents are asked to answer "yes" or "no" to the question: Would you continue to use this recreation area if the cost to you was to increase by X dollars? The amount is varied up or down in repetitive questions, and the highest positive response is recorded. Individual responses may then be aggregated to generate a demand curve for the recreation services provided by the area.

It seems reasonable that bidding games may be adapted to the estimation of the benefits from provision of an inexhaustible nonmarket good such as abatement of aesthetic environmental damage. Bidding games would seem to be the most direct method of estimating Bradford's aggregate benefit curve, which is derived from vertical summation of individual bid curves. The difficulties of interpretation which are inherent in the revealed demand techniques developed thus far do not occur when the bidding game technique is used. The data obtained with bidding games are not cost observations but individuals' perceptions of value. Thus, bidding games can be used in situations where direct costing techniques are ineffective for lack of data. These advantages of bidding games over revealed demand and direct costing techniques seem sufficient to justify attempts to adapt the bidding game technique for use in valuation of aesthetic environmental improvements.

Some General Considerations in the Design of Bidding Games

Bidding games are designed to elicit information on the hypothetical behavior of respondents when faced with hypothetical situations. In the case study presented below, the purpose of bidding games is to provide a measure of the benefits of aesthetic environmental improvements by measuring the willingness of a sample of respondents to pay for such improvements. The efficacy of bidding games used for this purpose depends on the reliability with which stated hypothetical behavior is converted to action, should the hypothetical situation posited in the game arise in actuality.

Willingness to pay is the behavioral dimension of an underlying attitude: concern for environmental quality.[7] Sociologists and public opinion researchers have built up a substantial body of literature which considers ways in which survey techniques of measuring attitudes and their behavioral component can be made as reliable as possible. Some desirable characteristics of such surveys have been identified [5, 9]. The hypothetical situation presented should be realistic and credible to respondents. Realism and credibility can be achieved by satisfying the following criteria for survey instrument design: Test items must have properties similar to those in the actual situation; situations posited must be concrete rather than symbolic; and test items should involve institutionalized or routinized behavior, where role expectations of respondents are well defined. Where the behavioral predisposition under study are affected by attitudes about a number of different things, the test instrument must be designed to focus upon those attitudes which are relevant. An example may be helpful. In the case study reported here, willingness to pay additional taxes to achieve aesthetic environmental improvement is affected by attitudes toward environmental quality, but also by attitudes toward the current tax burden and attitudes toward the idea of receptors of pollutants paying to obtain abatement of emissions. If the survey is carried out for the purpose of measuring the benefits of abatement, the test instrument must be designed to take cognizance of the various diverse attitudes which affect willingness to pay and to allow isolation of the relevant attitudinal dimensions.

Since abatement of aesthetic environmental damage is an inexhaustible, public good, bidding games intended to provide data for valuation of that good must be designed to avoid the effects of the freeloader problem, which encourages nonrevelation of preferences. One method would be to design games in which each respondent is told that all consumers of the good would pay for it on a similar basis, thus eliminating the possibility of freeloading.

With careful design of bidding games to ensure that the responses recorded are predictive of behavior, it should be possible to use the bidding technique to estimate the benefits of environmental improvements with reasonable accuracy.

AN EMPIRICAL APPLICATION: ESTIMATION OF THE BENEFITS OF ABATEMENT OF AESTHETIC ENVIRONMENTAL DAMAGES ASSOCIATED WITH THE FOUR CORNERS STEAM ELECTRIC GENERATING PLANT

At New Mexico State University, research is under way to examine the socioeconomic impacts of development of the rapidly expanding coal strip-mining and steam electric generation industry in the Four Corners Region (southwestern United States), and to predict the impacts of alternative policies with respect to environmental management and economic development, as such policies would affect the industry. One facet of this research required estimation of the benefits of abatement of aesthetic environmental damage associated with the Four Corners power plant at Fruitland, NM, and the Navajo mine which provides its raw energy source—low energy, low sulfur, high ash, sub-bituminous coal.[8]

[7] Three dimensions of attitudes are recognized [8]: (1) a cognitive dimension, (2) an affectual dimension, and (3) a behavioral dimension.

[8] The following facts may provide some idea of the magnitude of this operation and its attendant environmental problems. In 1970, the power plant had a capacity of 2,080 MW. The mine provides

The mine–power plant complex causes several kinds of aesthetic environmental damage. Particulates, sulfur oxides and nitrous oxides are emitted into the air. The adverse effects of particulate pollutants on visibility is considered the most important aesthetic impact of the complex. The strip-mining process will create some aesthetic damage. Although the soil banks will be leveled, reclamation in the sense of re-establishing a viable plant and animal eco-system is uncertain. Transmission lines radiate from the plant in several directions, passing through the Navajo Reservation and bringing the paraphernalia of development to a landscape which is in some places very beautiful and otherwise untouched.[9]

It was decided to use bidding games to measure the benefits of abatement of the aesthetic environmental damage associated with the Four Corners power plant and the Navajo mine.[10] Considerable attention was devoted to the design and development of bidding games which provide a reliable estimator of these benefits.

Questionnaire Design

The bidding games were part of prepared schedules designed for use in a personal interview survey of samples of users of the Four Corners Interstate Air Quality Control Region environment (i.e., residents and recreational visitors to the region). In preparation for the bidding games, respondents were asked a series of questions about environmental matters, to focus their attention on that topic. Then, the subject of the coal–electricity complex in the Four Corners area was explicitly raised. The respondents were shown three sets of photographs depicting three levels of environmental damage around the Four Corners Power Plant, near Fruitland, NM.

Set A showed the plant circa 1969, prior to installation of some additional emissions control equipment, producing its historical maximum emissions of air pollutants. Another photograph depicted the spoil banks as they appear following strip-mining, but prior to leveling. A third photograph showed electricity transmission lines marring the landscape. Set A depicted the highest level of environmental damage, and accurately represented the actual situation in the early years of operation of the plant.

Set B showed an intermediate level of damage. One photograph showed the plant circa 1972, after additional controls had reduced particulate emissions (i.e., the type of emissions most destructive of visibility). Another showed the spoil banks leveled but not revegetated; a third showed the transmission lines placed less obtrusively (i.e., at some distance from major roads).

Set C was intended to depict a situation where the industries continued to operate,

coal at a rate of 8.5 millions tons annually. Over the 40 year projected life span of the mine, 31,000 acres will be stripped. In 1970, approximately 550 people were employed in the mine and power plant, total value of sales of electricity was $146 million, and 96,000 tons of particulates, 73,000 tons of sulfur oxides and 66,000 tons of nitrous oxides were emitted annually.

[9] To place this aesthetic environmental damage in perspective, it may be useful to point out that the Four Corners Interstate Air Quality Control Region includes the greatest concentration of National Parks and Monuments in the United States and a number of Indian reservations, the largest of which are the Navajo and Hopi reservations. The value of the region for tourism and recreation depends largely on its bizarre and unusual landscapes, the enjoyment of which requires excellent long distance visibility and depth and color perception. There exists a substantial minority of "traditional" Native Americans who have strong religious and cultural attachments to nature, and who resent the air pollution, strip-mining, and transmission lines; witness the prolonged litigation about location of the Tucson Gas and Electric Company transmission line from the San Juan power plant, which is under construction about 9 miles from the Four Corners plant.

[10] In that part of the overall study which deals with nonaesthetic environmental damage, direct costing techniques are used.

but with minimal environmental damage. One photograph showed the plant with visible emissions reduced to zero.[11] A second photograph showed a section of arid land in its natural state; it was intended to depict a situation where the transmission lines were placed underground and the strip-mined land completely reclaimed.

The interviewers pointed out the salient features of each set of photographs to each respondent. For most of the respondents (with the exception of many recreationists), the situations were rooted in real experience: the residents of the region were familiar with the plant and mine, and their operation for the previous eight years. Most remembered situation A well, for that was exactly how it was only a few years earlier. Situation B was a fairly good approximation of the real situation at the time of the interviews. With the help of the photographs, situation C would be readily visualized.

Since the fitting of bid or benefit curves requires an expression of willingness to pay for abatement of aesthetic damages, it was necessary to design games based upon appropriate vehicles of payment. The vehicles for payment were chosen so as to maximize the realism and credibility of the hypothetical situation posited to respondents. As will be discussed below, it was necessary to design and use a series of bidding games, because no one vehicle of payment was appropriate for use with all of the subpopulations sampled. First, the general format applicable to all games is discussed. Then, the particular games used for particular subpopulations are discussed.

For each bidding game played, respondents were asked to consider situation A, the highest level of environmental damage, as the starting point. The bidding games were designed to elicit the highest amount of money which the respondent, an adult speaking for his or her household, was willing to pay in order to improve the aesthetic environment to situation C, and to situation B. Answers were elicited in terms of "yes" or "no" to questions expressed in the form "would you pay amount X . . . ?" A "yes" answer would lead the enumerator to raise the amount and repeat the question, maybe several times, until a "no" answer was obtained. A "no" answer would lead the enumerator to reduce the amount until a "yes" answer was obtained. The amount which elicited the highest "yes" answer was recorded as the amount the respondent was willing to pay.

It was emphasized that the respondent was to assume that the vehicle for payment used in a particular game was the only possible way in which environmental improvements could be obtained. This stipulation was designed to minimize the incidence of zero bids as protests against either the zero liability rule implicit in "willingness to pay" games or the particular method of payment used in a particular game. If a respondent indicated that he was willing to pay nothing at all, he was asked a series of questions to find out why. A respondent indicating that he did not consider his household to be harmed in any way by the environmental damage and, therefore, saw no reason to pay for environmental improvements was recorded as bidding zero. If a respondent indicated that his zero bid was in protest against the game, his answer was analyzed as a nonresponse to the bidding game, since he had refused to play the game by the stated rules.[12]

[11] This feat was accomplished by photographing the plant on a day when all units were shut down.

[12] For the purpose of estimating the benefits of abatement, the treatment of "protest bids" as nonresponses is legitimate. By definition, a "protest bid" recognizes that positive benefits from abatement exist, but registers a protest against a particular method of financing abatement. We recognize that the elimination of "protest bids" from analyses aimed at estimating the benefits of abatement fails to remove all downward bias from the responses to particular games: some respondents may bid low (i.e., underestimate the benefits to themselves of abatement) in conscious or subconscious protest against the method of financing assumed in a game.

The selection of appropriate vehicles for payment provided a challenge. People are not accustomed to paying for abatement of air pollution and strip-mining damage. However, they are accustomed to paying for many other types of useful goods and services, many of which, such as parks and highway beautification, have aesthetic or "quality of life" components. So selection of realistic vehicles for payment was not impossible. However, the heterogeneous nature of the affected population meant that no single vehicle was suitable for data collection among all groups. In the Four Corners Region, the affected population can be divided into three broad groups: (1) the residents of Indian reservations, primarily Navajos, but also including members of several other tribes; (2) the residents of the nonreservation sections of the region, primarily Anglo-Americans, but with a sprinkling of Spanish-Americans, Native Americans living off the reservations, and other minorities; and (3) the tourists and recreationists who visit the area to enjoy its unique natural, historical and cultural attractions. Different versions of the questionnaire, using bidding games based on different vehicles for payment, were constructed for use with the three different subpopulations of the affected population.

The particular bidding games used are described below.

The sales tax game. Members of all three subpopulations are familiar with the practice of paying sales taxes. For most, this is a frequent occurrence. It is also understood by most that income collected in sales taxes is used to provide useful public services. It does not require much imagination to conceive of a public agency collecting a sales tax from residents of the affected region and using the income to finance environmental improvements.

The sales tax bidding game was used for both the resident samples. It was not used with the recreationist sample, since that group often purchased only a few items in the region, bringing most of their equipment and supplies with them. This would make a regional sales tax largely irrelevant for that group.

Respondents were asked to assume that a regional sales tax was collected on all purchases in the Four Corners Interstate Air Quality Control Region for the purpose of financing environmental improvements.[13] All revenue from the additional tax would be used for abatement of aesthetic environmental damage associated with the power plant and mine, and all citizens would be required to pay the tax. Recreational visitors to the region would contribute to environmental improvement through payment of additional users fees for facilities.

The electricity bill game. The monthly electricity bill seemed to be a suitable vehicle for measurement of willingness to pay. It is the production of electricity which causes the environmental damage, and most people can readily comprehend that reduction of the damage may raise the cost of operating the industry and that passing these additional costs on to consumers of electricity is a not unlikely outcome. For the residents of those sections of the region outside the Indian reservations, payment of a monthly electricity bill is a routinized behavior. Therefore, a bidding game based upon the monthly electricity bill was played with the nonreservation resident sample.

This game was unsuitable for use with the other two samples. Many residents of

"Protest bids" were recorded and used in some other types of analyses. For example, the incidence of "protest bids" is an indicator of the relative political acceptability of various methods of financing abatement.

[13] The regional sales tax would be additional to current state and local sales taxes and would be charged on all commodities subject to existing state and local sales taxes.

Indian reservations do not have electricity available in their homes. Recreationists do not pay monthly electricity bills while vacationing away from home.

The respondent was first asked the amount of his monthly household electricity bill. He was then asked to imagine that an additional charge was added to his electricity bill, and the electricity bills of everyone who uses electricity produced in the Four Corners Region, even people as far away as southern California. All of the additional money collected would be used to repair the aesthetic environmental damage caused as a result of electricity production and transmission in the Four Corners region.

The user fees game. Measuring recreationists' willingness to pay for environmental improvements raised problems which prevented use of the electricity bill and sales tax games. For the recreationists, a satisfactory game would need to focus upon (1) the activities associated with vacationing, and (2) the collection of payments while they are in the region and using the regional environment. The payment of user fees for recreation services (i.e., campsite, utilities hook-up, boat launching), seemed to be a promising vehicle for a bidding game for the recreationists. If visitors were concerned about environmental quality in the places where they vacation, the payment of an additional sum along with their usual daily user fees would provide a suitable way to express that concern.

A sample of recreationists in the national parks, monuments and forests and state parks in the region played a bidding game based on user fees. Only recreationists who were not residents of the region were included. They were first asked the total sum of user fees they paid daily. They were then asked to suppose user fees in all the recreation areas in the Four Corners area were increased. All the additional money collected would be spent on environmental improvements. All recreators would pay and the year-round residents would pay, too, through additional regional sales taxes.

The Conduct of the Survey

The bidding games, as described above, were included in prepared schedules which also served as the instrument for collection of data for socioeconomic analysis of citizen environmental concern. Personal interviews were conducted by enumerators who were closely supervised and who had been carefully trained in formal sessions and in two separate field pre-tests of the questionnaire. Interviews were conducted during the summer of 1972.

Usable questionnaires were completed by 526 residents of nonreservation sections of the Four Corners Interstate Air Quality Control Region, 71 residents of Indian reservations and 150 recreators and tourists from outside the region who were using recreation sites within the region. The ratio of reservation residents to nonreservation residents sampled was proportional to their total numbers in the regional population; the size of the recreationist sample was chosen arbitrarily. Respondents from each subpopulation were selected by stratified random sampling. Stratification was based on concentration of air pollutants above the respondent's home or recreation site, as estimated by an atmospheric diffusion model developed as part of the larger research project. The population in higher pollution concentration zones was sampled more heavily.

Analysis and Results

For the *determination of three points on the aggregate bid curve,* corresponding to the situations, A, B, and C, the bidding game results were aggregated by methods appro-

TABLE I

AGGREGATE BIDS FOR ABATEMENT OF AESTHETIC ENVIRONMENTAL DAMAGE ASSOCIATED WITH THE FOUR CORNERS POWER PLANT, 1972

Item	Situation		
	A	B	C
Emissions (tons of particulates per year)	96,000	26,000	0
Level of abatement (tons of particulates per year)	0	70,000	96,000
Estimated regional aggregate bid ($ millions per year)	0	15.54	24.57
Standard error ($ millions per year)	—	1.24	1.52
95% Confidence limits ($ millions per year)	—	±2.43	±2.97
Estimated consumer aggregate bid ($ millions per year)	0	11.25	19.31
Standard error ($ millions per year)	—	0.68	0.98
95% Confidence limits ($ millions per year)	—	±1.33	±1.92

priate to the stratified random sampling technique used, to provide estimates of the total bid for the relevant population. Two methods of aggregation were used, to generate two different aggregate bid curves.

(1) The results of the sales tax game with area residents (reservation and non-reservation) were added to the results of user fee games played by recreators to estimate a total regional willingness to pay for three levels of environmental improvement.

(2) The results of the electricity bill game were extrapolated over all consumers of power from the Four Corners plant to estimate consumer willingness to pay. This latter procedure involved the ethical premise that, since the production of electricity causes environmental damage, all citizens who consume Four Corners power ought to be willing to pay as much in additional electricity charges for environmental improvements as those who live in the region which suffers the damage. However appealing this ethical premise may be, our survey did not include people outside the region. Thus the consumer bid cannot be interpreted as an estimate of true "willingness to pay." It would be interesting to extend this research to include bidding games for these consumers of Four Corners electricity who do not live or recreate in the affected environment.

While both the regional and consumer aggregate bids are of interest, the authors believe that more faith may be placed in the regional bid since that bid was derived from samples of all segments of its relevant population.

Table I presents the estimated aggregate bids, standard errors, and 95% confidence limits at points A, B, and C. Regional and consumer bids are presented.

Using the estimated aggregate bids (Table I), a *regional aggregate bid curve* and a *consumer aggregate bid curve* were fitted. To fit two-dimensional aggregate bid curves, it was necessary to select a single independent variable to serve as a proxy for the total package of aesthetic environmental improvements under consideration. Situations A, B, and C were defined so that all three forms of aesthetic damage (air pollution, strip-mining, and transmission lines) were successively reduced together from their most obtrusive in situation A to virtual elimination in C. Of the three forms of damage, reduced visibility due to particulate air pollution was considered by respondents to be far and away the most serious. So, abatement of particulate air pollutant emissions (measured as the difference, in tons per year, between the level at A and the levels at

TABLE II

TESTS OF HYPOTHESES CONCERNING THE SLOPES OF THE AGGREGATE BID CURVES

Hypothesis	Confidence of rejecting H_0	
	Regional aggregate bid curve (%)	Consumer aggregate bid curve %)
1. The aggregate bid curve is of linear positive slope[a]	99.9	99.9
2. The aggregate bid for situation B is one half of that for C[b]	99.9	94.5

[a] Rejection implies that the aggregate bid curve is of increasing positive slope.
[b] Rejection implies that the aggregate bid for B exceeds one half of that for C.

B and C, respectively) was arbitrarily chosen to serve as a single independent variable for graphical analyses.[14]

The form of the curve requires some discussion. It has already been noted [footnote 2] that the usual restraints placed on the slope of demand curves are inappropriate for the first derivatives of aggregate bid curves for public goods, due to the impossibility of separating quantity and quality factors. Here we have a case in point. It seems resonable that "consumers" of abatement of particulate emissions desire the attribute, visibility. Given the reasonable assumption that marginal utility of additional visibility is diminishing, one would expect the first derivative of the aggregate bid curve for visibility to be of negative slope.

Meteorologists have established that an inverse relationship exists between visibility and concentration of particulate pollutants. Visibility increases at an increasing rate as particulate pollution (measured in terms of weight) is abated [3, 10]. Therefore, the slope of the marginal aggregate bid curve for abatement of emissions (in tons per year) is *a priori* unpredictable, since the diminishing marginal utility of visibility and the increasing marginal visibility resulting from additional abatement influence that slope in opposite ways.

In terms of visibility, the aggregate bid curve form which provided the best fit of the three data points was

$$B = c \ln (v),$$

where B = aggregate bid in dollars, c = a constant, and v = visibility.

In terms of abatement of particulate air pollutants (measured in tons per year), the appropriate curve form was

$$B(q) = c \ln \frac{k}{k - q},$$

[14] In the case study at hand, we recognize the inelegance introduced by this procedure. We do not believe it does serious violence to the truth, since most of the aesthetic environmental damage occurring is, in fact, due to particulate air pollutants. We emphasize, however, that this problem should not typically occur in the use of aggregate bid methodology and bidding game techniques. Rather, its occurrence here was a special case and is attributable to our need to value a package of different aesthetic environmental improvements within the following constraints: (1) a limited research budget, which confined us to one personal interview survey, and (2) the need to limit the length of each interview, to avoid exhausting the patience of respondents.

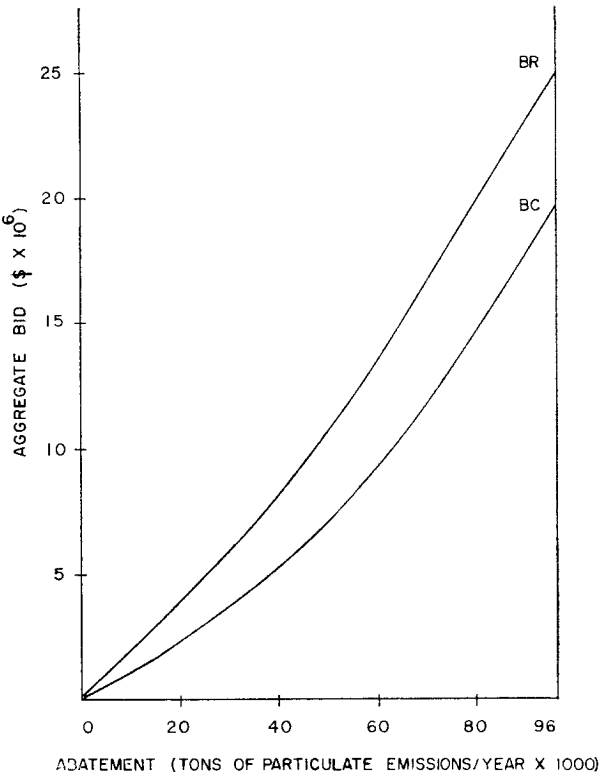

FIG. 2. Estimated aggregate bid curves for abatement of aesthetic environmental damage, Four Corners power plant, 1972. BR, Regional aggregate bid; BC, Consumer aggregate bid.

where k = a parameter relating visibility to emissions, which is determined behaviorally, and q = tons of particulate emissions abated annually.

The aggregate bid curve fitted using this equation form passes through the origin, as logically it must, given that rational citizens would bid zero for zero abatement. The first derivative of the aggregate bid curve is of positive slope.[15] Statistical tests (Table II) resulted in rejection of the hypotheses (1) that the aggregate bid curve was linear, or of decreasing positive slope, and (2) that the aggregate bid at point B was simply one-half of that at C. Regional and consumer aggregate bid curves are presented (Fig. 2).

[15] It must be emphasized that the curve form used provided the best fit, given the three data points available. It would have been desirable to have collected information adequate to generate more data points. The decision to collect data for only three points was made in recognition of limits to the patience of respondents. The multipurpose schedule was already quite lengthy, given the need to collect data relevant to the situation of the respondent, play the bidding games, and collect socio-economic, sociological and attitudinal data.

It is recognized that, if more data points had been available, a different curve form may have been appropriate. The possibility of a sigmoid aggregate bid curve is logically appealing. Such a curve would have a segment of increasing slope, where the increasing marginal visibility from particulate abatement dominates the decreasing marginal utility of additional visibility then, as complete abatement is approached (i.e., somewhere to the right of our point B), the slope may become decreasing as the diminishing marginal utility of visibility becomes dominant. Such a curve form would be consistent with theoretical considerations and with the three data points available.

The fitted aggregate bid curves were:

$$B_r = \$29{,}175{,}840 \ln \frac{168{,}890}{168{,}890 - q}, \quad \text{for the regional aggregate bid curve, and}$$

$$B_c = \$15{,}396{,}700 \ln \frac{134{,}490}{134{,}490 - q}, \quad \text{for the consumer aggregate bid curve.}$$

Marginal aggregate bid curves, or *price curves*, were generated by taking the first derivatives of the aggregate bid curves (Fig. 3). The derived price curves were:

$$P_r = \$\frac{29{,}175{,}840}{168{,}890 - q}, \quad \text{derived from the regional aggregate bid curve, and}$$

$$P_c = \$\frac{15{,}396{,}700}{134{,}490 - q}, \quad \text{derived from the consumer aggregate bid curve.}$$

These derived price curves are very useful for public policy analyses with respect to optimal environmental management policies. In Fig. 4, a hypothetical derived price curve is presented, along with a hypothetical marginal cost of abatement curve. In this hypothetical example, the optimal level of abatement is S. A standard allowing maxi-

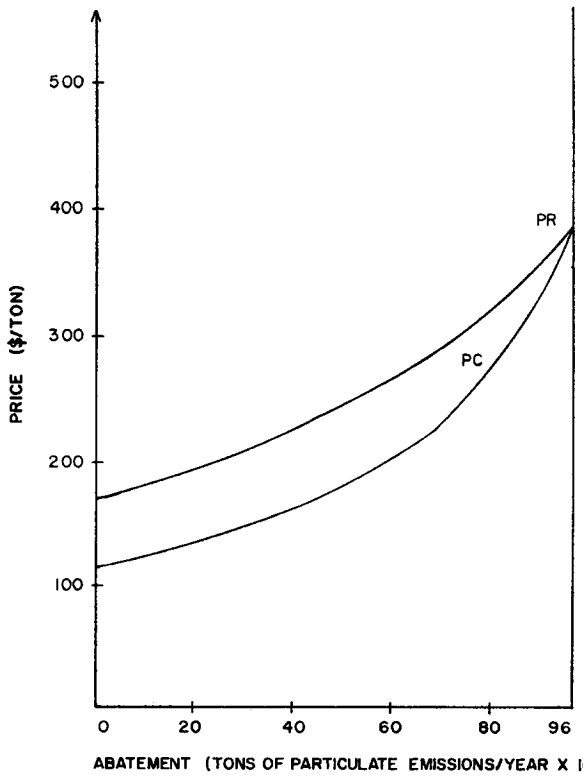

FIG. 3. Derived price curves for abatement of aesthetic environmental damage, Four Corners power plant, 1972. PR, price curve derived from regional aggregate bid; PC, price curve derived from consumer aggregate bid.

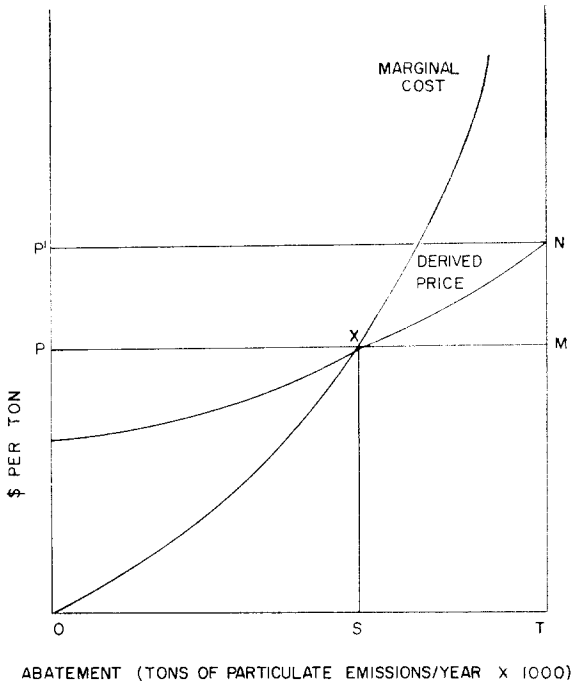

FIG. 4. Optimal standards, penalties and per unit taxes on emissions, given hypothetical marginal cost and price curves.

mum annual emissions of $(T–S)$ tons of particulates would be appropriate, and the penalty for violation of that standard should be set sufficiently high that the polluter's expected penalty per ton of emissions in excess of the standard would be at least P. An alternative institutional framework would call for a fine or tax per ton of particulate emissions. The fine ought to be set at least as high as P per ton. At the level P, the optimal level of abatement would be achieved. A fixed fine per ton of remaining emissions would result in collection of the amount $XMTS$. However, since the derived price curve is of positive slope, the sum of the fines collected would be insufficient to compensate the receptors of the pollutants for their loss in welfare. The necessary amount would be $XNTS$. This amount could be collected, if full compensation were the accepted policy,[16] by using a sliding scale of fines, ranging from P' for the first ton of emissions down to P for all emissions in excess of $T–S$.

If the marginal costs of abatement of aesthetic environmental damage associated with the Four Corners power plant were known,[17] the derived price curves presented

[16] Under a full compensation policy, a derived price curve generated from bidding games based on the concept of willingness to pay (which implicitly places the liability with the receptor of damages) would underestimate both the optimal level of abatement and the appropriate level of fines or taxes. Randall [15] and others have demonstrated that the demand for abatement of an external diseconomy is greater in the full liability situation than in the zero liability situation implicit in willingness to pay games.

[17] We are not yet in a position to present a complete benefit/cost analysis of the abatement of the aesthetic environmental damage associated with the Four Corners power plant and Navajo mine. Preliminary and tentative calculations indicate that, *if our attribution of most of the benefits reported here to abatement of particulate air pollutants is reasonable*, 99.7% abatement of particulate emissions (the current New Mexico standard for 1975) is economically justified on the basis of aesthetic considerations alone. Some additional abatement beyond the 1975 standard may be justified. The economic benefits from that abatement which has already taken place appear to far exceed the costs.

TABLE III

INCOME ELASTICITY OF BID FOR ABATEMENT OF AESTHETIC DAMAGES ASSOCIATED WITH THE FOUR CORNERS POWER PLANT, 1972

Subpopulation	Game	Level of abatement	Income elasticity of bid	Standard error	Significantly greater than zero[a]?
Nonreservation residents	Sales tax	B	0.65	0.10	Yes
		C	0.65	0.08	Yes
Reservation residents	Sales tax	B	0.23	0.18	No
		C	0.24	0.18	No
Nonreservation residents	Electricity bill	B	0.54	0.09	Yes
		C	0.39	0.06	Yes
Recreators	Users fees	B	0.09	0.15	No
		C	0.16	0.11	No

[a] At the 95% level of confidence.

in Fig. 3 could be used to perform policy analyses similar to those in the hypothetical example above.

The *relationship between willingness to pay and household income* is of interest. However, the concept of income elasticity of demand is inappropriate to the public good under study. The calculation of an income elasticity of quantity of abatement demanded would require consideration of the relationship between income and quantity of homogeneous units of abatement demanded at a constant price per unit. However, in this study there were no explicit unit prices for abatement; neither were there individual variations in quantity of abatement demanded, as the quantities were fixed as defined in situations A, B, and C. These conditions result from the inherent nonexclusive nature of abatement of aesthetic environmental damage: Everyone obtains the same quantity and there is no explicit price. This situation is the inverse of the market situation for private goods; dollar bids are the response to a quantity which is given.

Since there existed no market price at which to calculate the income elasticity of demand, an "income elasticity of bid" was estimated. The income elasticity of bid was defined as:

$$e_Y = \frac{dB}{dY}\frac{Y}{B} = b_1\frac{Y}{B},$$

where Y = household income, and B = the individual's total annual bid. A linear regression model was used to determine the statistic b_1. The mean value of Y and B were used, and the calculation was made at each level of abatement.

Calculated income elasticities of bid for the various subpopulations and bidding games are presented in Table III. In all cases, income elasticity of bid was greater than zero, indicating that higher income households were willing to pay a greater amount than lower income households to achieve the same level of abatement of aesthetic damages. For the non-reservation residents, calculated income elasticity of bid

This conclusion is extremely tentative and subject to revision. It is presented in this footnote (at the request of an anonymous reviewer) to provide a "ball park" indication of the conclusions which may arise from our research.

ranged from 0.39 to 0.65, depending on the game and the level of abatement. Income elasticity of bid was significantly greater than zero at the 95% level of confidence. For the residents of Indian reservations and the recreational visitors to the region, lower positive income elasticities were recorded. These were not significantly greater than zero, at the 95% level of confidence.[18]

It was also found that willingness to pay an additional charge in the electricity bill for a particular level of abatement increased as the size of the electricity bill increased. Electric bill elasticity of bid, as defined as

$$e_b = \frac{dB}{d\text{Bill}} \frac{\text{Bill}}{B},$$

was calculated (for the nonreservation resident sample) to be 0.30 for situation B and 0.25 for situation C; at both points, it was significantly greater than zero at the 95% level of confidence. These estimates indicate that willingness to pay for a given level of environmental improvements increased as the size of the electricity bill increased, but at a lesser rate.

The Reliability of the Results

In the statistical sense, our estimates of the aggregate benefits from abatement of aesthetic environmental damage would seem to be of a high order of reliability. The 95% confidence limits of the aggregate bids are quite narrow, compared with the size of the estimated aggregate bids. Statistical estimates of the confidence which may be placed in these estimated aggregate bids are based upon the variance of the responses of the samples, and indicate the confidence with which sample results may be extrapolated to the whole population. These statistics, *per se*, are unable to give any indication of the reliability with which predispositions to behave, as measured by the bidding games, would be transmitted to actions should the hypothetical situation arise.

We argue, nevertheless, that our estimates of the benefits of abatement of aesthetic environmental damages associated with the Four Corners power plant are of a reasonable order of magnitude and, if anything, conservative. (1) We believe the design of the bidding games allows confidence in their efficacy. (2) The individual household bid for abatement, on average, is of the same order of magnitude as the estimates of the value of particulate pollution abatement obtained in revealed demand studies [1], when the latter are converted to a comparable basis. Mean individual household willingness to pay for abatement, measured by the sales tax game played with the nonreservation resident sample, was about $50 annually to achieve situation B and $85 annually to achieve situation C. (3) The estimated aggregate bids for abatement are relatively small given the scale of the operation at Four Corners, as indicated by its 1970 emissions rate and its total annual sales of $146 million [footnote 5]. (4) Theoretical analyses indicate that the demand for abatement of an externality will

[18] The estimates of income elasticity obtained with the nonreservation resident sample may be more reliable, for two reasons. First, the nonreservation sample was considerably larger than either of the other two samples. Second, the range of incomes encountered in the nonreservation resident sample more nearly approached that of society as a whole. The reservation resident sample was representative of its underlying population, in which incomes are concentrated at the extreme lower end of the national range. The visiting recreators had a mean household income about fifty per cent greater than the national average; very few recreators had incomes in the lower half of the national range.

be lower under a zero liability rule than under intermediate or full liability rules [15]. The bidding games used were based on zero liability rules, and they should be expected to yield conservative estimates of the benefits of abatement.

It is recognized that three data points provide an inadequate basis on which to draw conclusions with respect to the shapes and slopes of the aggregate bid curves and their first derivatives. However, it is consistent with theoretical considerations and with the limited data available that the aggregate bid curves may have at least a segment with increasing slope.

It would seem that the income elasticity of bid and the electric bill elasticity of bid fall in the range from zero to -1. This result was consistent with our prior expectations.

CONCLUDING COMMENTS

In the case study reported, bidding games were used to estimate the benefits which would accrue from abatement of the aesthetic environmental damages associated with the Four Corners power plant and the Navajo mine. The problem situation was not amenable to the use of direct costing nor revealed demand techniques.

This study has revealed that substantial benefits may be gained from abatement of aesthetic environmental damage associated with the Four Corners power plant and Navajo mine. These potential benefits have not been revealed or realized in the market place. However, the process of political and institutional change has led to the imposition of increasingly rigorous control standards for particulate emissions from the plant, indicating a recognition, in some broad sense, that benefits may be gained from emissions controls. Our contribution has been to attempt a quantification of these benefits.

We believe that the use of bidding game techniques was successful in meeting the objective, valuation of these benefits. Bidding game techniques seem amenable to use as a research tool for valuation of a wide variety of nonmarket goods. It must be understood, however, that bidding games measure the hypothetical responses of individuals faced with hypothetical situations. Thus, considerable care must be exercised in the design of bidding games and the conduct of surveys for data collection, to ensure that the results obtained are as reliable as possible.

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