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Volume IV, Studies on Partial Equilibrium Approaches to Valuation of Environmental Amenities

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METHODS DEVELOPMENT FOR ASSESSING AIR POLLUTION CONTROL BENEFITS

Volume IV

Studies on Partial Equilibrium Approaches to Valuation of Environmental Amenities

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OTHER VOLUMES OF THIS STUDY

Volume I, Experiments in the Economics of Air Pollution Epidemiology, EPA-600/5-79-001a.

This volume employs the analytical and empirical methods of economics to develop hypotheses on disease etiologies and to value labor productivity and consumer losses due to air pollution-induced mortality and morbidity.

Volume II, Experiments in Valuing Non-Market Goods: A Case Study of Alternative Benefit Measures of Air Pollution Control in the South Coast Air Basin of Southern California, EPA-600/5-79-001b.

This volume includes the empirical results obtained from two experiments to measure the health and aesthetic benefits of air pollution control in the South Coast Air Basin of Southern California.

Volume III, A Preliminary Assessment of Air Pollution Damages for Selected Crops within Southern California, EPA-600/5-79-001c.

This volume investigates the economic benefits that would accrue from reductions in oxidant/ozone air pollution-induced damages to 14 annual vegetable and field crops in southern California.

Volume V, Executive Summary, EPA-600/5-79-001e.

This volume provides a 23 page summary of the findings of the first four volumes of the study.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

DISCLAIMER

PREFACE

The research studies presented in this volume emphasize some factors that are not completely treated in previous volumes. Most of the independent studies presented here tend to qualify the results of the experimental procedures set forth in earlier volumes. Each of them is therefore worthy of detailed attention.

ABSTRACT

The research presented in this volume explores various facets of the two central project objectives (the development of new experimental techniques for measuring the value of impovements in environmental amenities; the use of microeconomic methods to develop hypotheses on disease etiologies, and to value labor productivity and consumer losses due to air pollution-induced mortality and morbidity that have not been given adequate attention in the previous volumes. The valuations developed in these volumes have all been based on a partial equilibrium framework. W.R. Porter considers the adjustments and changes in underlying assumptions these values would require if they were to be derived in a general equilibrium framework. In a second purely theoretical paper, Robert Jones and John Riley examine the impact upon the aforementioned partial equilibrium valuations under variation in consumer uncertainty about the health hazards associated with various forms of consumption.

Two empirical efforts conclude the volume. M.L. Cropper employs and empirically tests a new model of the variations in wages for assorted occupations across cities in order to establish an estimate of willingness to pay for environmental amenities. The valuation she obtains for a 30 percent reduction in air pollution concentrations accords very closely with the valuations reported in earlier volumes.

The volume concludes with a report of a small experiment by W.R. Porter and B.J. Hansen intended to test a particular way to remove any biases that bidding game respondents have to distort their true valuations.

All of these studies tend to qualify the results of the experimental procedures discussed in earlier volumes. Further research will require: (1) an adequate specification of the mobility decision in response to degraced air quality; (2) consideration of relative price changes not directly related to air pollution as set forth in Chapter II and verified by Porter; and (3) how consumers evaluate a multitude of risks simultaneously, both in eating habits and pollution exposures where their economic and physical losses are uncertain.

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CHAPTER II

PUBLIC GOODS DECISIONS WITHIN THE CONTEXT OF A GENERAL COMPETITIVE ECONOMY

by
William R. Porter

The purpose of this paper is to analyze the problem of public goods decision-making within the context of a general competitive economy for private goods. It is related to, but quite different from, recent works on the theory of value in economies with public goods.1/ The focal point of those works is the theoretical relationship between a Lindahl equilibrium and the core or Pareto optimum. Here we deal with the more mundane matter of what is involved in making a public goods production decision that will move the economy from its current equilibrium allocation to one that is Pareto superior. The theoretical techniques used are similar to allocation techniques for a planned economy,2/ however, the situation differs because private goods allocation here is accomplished in competitive markets.

There are two major types of problems involved in public goods decisions that are not encountered in private goods decisions. The first is to determine the proper concept of public good valuation, since the market does not provide one as it does in the case of private goods. The second is to obtain correct information about people's preferences concerning public goods in order to use the chosen valuation concept. Again the market normally does not provide this information, and the individuals usually have strong incentives to conceal or misrepresent their preferences.

The two problems are present when dealing with any public good (whether it is air pollution, public health, or national defense), therefore, although we are primarily interested in questions of environmental quality, the analysis and discussion will be presented in terms of an abstract public good.

The two problems are examined separately beginning with the determination of an appropriate valuation concept and a method of using that concept for decisionmaking when there is no problem of incorrect revelation of preferences. The framework for analysis is a general competitive economy model with public goods, but the ultimate object is to obtain results that will be -useful in making real decisions on public goods allocation.

Many of the currently used concepts and methods of applied cost-benefit analysis have their theoretical foundations in partial equilibrium models. Therefore, it is quite possible that their use in a general economy having interactions among markets can lead to misallocation problems.

It has long been recognized by practitioners of cost-benefit analysis that the public good decision will have secondary effects on related markets therefore rendering the partial equilibrium methods inappropriate. However, this has not led to the development of general equilibrium methods for several reasons.

1. Many of the public good projects are small compared with the size of the overall economy, and therefore the secondary effects are thought to be small by comparison.

2. The possible complexity of a method that would try to model all the general equilibrium interactions would be unmanageable for applied work.

3. The tendency to separate the calculation of project benefits from those of project costs makes it seem that public good decisions deal more with the production of a scaler called net surplus rather than with the redistribution of vectors of commodities.

4. And among economists who have been interested in general economies with public goods and externalities, there has been an almost exclusive interest in the problems of existence of a competitive [Lindahl] equilibrium and its optimality properties, rather than in the problems facing the public decisionmaker of how to move from a non-optimal equilibrium to one that is Pareto superior.

This study uses the theoretical framework of a general competitive economy with public goods, however, the ultimate purpose is to obtain implications that will be useful in applications to real-world decision problems. We will look for ways in which the use of a general economy approach will yield results that are superior to the partial equilibrium methods. Therefore, efforts will be made to identify the types of errors that can arise when strictly partial equilibrium valuation methods are used in a general equilibrium economy. We will also propose ways in which the partial equilibrium methods can be modified in order to minimize the errors that are produced due to general equilibrium adjustments in the economy.

Before beginning the development of the basic model, we present the following example to illustrate the type of misallocation that can result from using partial equilibrium valuation measures in a general equilibrium context.

In a city plagued with air pollution, the property values in areas that are relatively free from pollution are quite high. The city government is considering a project that will uniformly reduce the average pollution levels throughout the city. It bases its acceptance of the project on whether the sum of people's valuations of the proposed pollution reduction exceeds the known cost of the project. The project is accepted, and the air pollution is reduced. After the pollution has been cleaned up, there is a general readjustment in property values resulting in large losses for the owners of the property that was previously "relatively free from pollution." These areas now have lower levels of pollution than before but they are not relatively so desirable. In view of the property value losses, these owners wish that the project had not been approved. If they could have anticipated the price changes that have occurred then their valuations would have been much lower and the project may not have been accepted.

The problem of unanticipated price changes due to the public good decision is more troublesome than is generally recognized for the following reasons.

1. It might be thought that the individuals could take the possibility of price changes into consideration when they evaluate the proposed public good project, however, there is really no way for the individual to do this since the new equilibrium prices after the project is completed depend on complex interaction of production technology and consumers' preferences which cannot be known by all individuals. Each person may be able to make a rough guess concerning the new prices, and that might reduce, but certainly would not eliminate, the possibility of misallocation due to imperfect price anticipation.

2. It is tempting to think that the problem is simply one of distribution where the losses of some are more than offset by the gains of others, and if the net surplus were appropriately redistributed then everyone would be better off than before. Unfortunately, movements from one general equilibrium to another are not so nicely behaved. It is entirely possible that even though the total apparent net surplus of the project, measured at the old equilibrium, is positive, the realized net surplus after the new equilibrium is reached is negative. Indeed, it is possible that everyone overvalued the public good project by assuming he could trade at the old prices.

3. The problem is not just one of using local measures of valuation for discrete changes. The difficulty is present even when discrete valuation measures are used. On the other hand, if the proposed public project is infinitesimal in size then the problem disappears.

In this air pollution example, it is important to note that the problem cannot be taken care of by using an estimate of the demand function for property. The property price change is simply used as an example, and it is important to realize that many other prices will change in a general adjustment. Furthermore, the estimate of the demand for property function will normally use data from a single equilibrium (in a cross-sectional study) which cannot reveal information about changes from one equilibrium to another.

To illustrate the problems of determining the proper level of public good production we examine a competitive market economy having two private goods and one public good. There are I consumers $i = 1,\ldots,I$, who each have constant endowment flows $\omega_i = (\omega_{i1},\omega_{i2})$ of the two private goods and strictly quasi-concave utility functions $u^i(x_i,z)$ defined on their own consumption of private goods $x_i = (x_{i1},x_{i2})$ and the amount available z of the public good. The level of public good z is produced according to the production function $z = f(y)$, where y is input of good 1.

Initially we assume that the government has perfect knowledge of the current market prices of private goods and the preferences of the individual consumers and is charged with the task of collecting the input of good 1 from the consumers in order to produce the proper level of the public good. (Note that the government's problem here is different than that of a central planner in that the private goods prices are determined in the market and are taken as given by the government).

We assume that the government's problem begins at a general equilibrium $[p,(x_i),z]$. Even though the level of the public good is not market determined and would not normally be thought of as a component of the general equilibrium, we include it here since it will be changing along with changes in the equilibrium prices p and allocation of private goods (x_i). The object is to specify a decision procedure that will use the collection of inputs of good 1 from consumers (taxation) and the production of the public good to bring about movement along a Pareto improving path toward a Pareto optimum. (Note that the tax used here is simply a flow of good 1 that is taken from each consumer independent of his own actions. In that sense it is a lump-sum tax).

<u>A Continuous Path Method</u>

In this simple model having only a single public good, the government's decision will deal only with the taxation problem since all of the proceeds of taxation must go into the single activity of public good production. The government's decision will be based on the individual marginal valuations of the public good defined as follows. At the equilibrium $[p,(x_i),z]$, person i's marginal valuation of the public good in terms of good 1 is:

$$v_i(x_i,z) = \frac{u^i_z(x_i,z)}{u^i_1(x_i,z)} = MRS_z \text{ for } 1 \qquad (2.1)$$

The <u>marginal social valuation</u> of the public good is defined as:

$$V(z) = \sum_{i=1}^{I} v_i \qquad (2.2)$$

The <u>social cost</u> of z units of the public good is:

$$C(z) = f^{-1}(z), \text{ where } f^{-1} \text{ denotes the inverse function of } f. \qquad (2.3)$$

The <u>marginal social cost</u> of the public good is:

$$C'(z) = [f^{-1}(z)]' \qquad (2.4)$$

Let s_i denote the total tax, in units of good 1, that person i is charged, and let γ_i be a non-negative weight that is assigned to person i, where $\sum_1 \gamma_i = 1$. The rate of change in the level of the public good is based on the magnitude of $[V(z) - C'(z)]$, which is called the <u>net marginal social</u>

valuation of the public good. The rate of change is given by:

$$\dot{z} \equiv \frac{dz}{dt} = \alpha[V(z) - C'(z)], \quad \text{where } \alpha > \tag{2.5}$$

Each person i's tax share is changed in such a way that he receives the share γ_i of the net social surplus resulting from the change. Therefore,

$$\frac{ds_i}{dz} = v_i - \gamma_i[V(z) - C'(z)], \quad \text{where } \gamma_i > 0 \text{ for all i, and } \sum_i = 1. \tag{2.6}$$

Summing over all individuals, we see that the sum of the tax changes is just sufficient to provide the necessary input C'(z) of good 1.

$$\sum_i \frac{ds_i}{dz} = \sum_i v_i - [V(z) - C'(z)]\sum_i \gamma_i$$

$$= V(z) - V(z) + C'(z) = C'(z). \tag{2.7}$$

No person is made worse off by the change, since each person's tax change is less than his own marginal valuation. Therefore, the procedure is continuously Pareto improving as long as the net marginal social valuation is non-zero.

The time rate of change in person i's tax is:

$$\dot{s}_i = \frac{ds_i}{dz} \cdot \frac{dz}{dt} = \alpha[v_i[V(z) - C'(z)] - \gamma_i[V(z) - C'(z)]^2]. \tag{2.8}$$

Equations (2.5) and (2.8) completely describe the time path of government action with respect to allocation in the economy. However, other reallocation is continuously occuring outside the domain of the government. As the level of the public good changes and taxes change, the consumers have incentive to adjust their private goods bundles through trade. Therefore, the government's actions are accompanied by continuously changing private goods prices. This fact is extremely important because if we think of an economy where private goods trading does not occur as the government changes taxes and the public good level, then the economy would not, in general, be at a Pareto optimum once the reallocation defined by (2.5) and (2.8) was complete.

The method of continuous government allocation in a three good economy can be easily generalized to more complicated economies having more private and public goods and a more general type of public good production function. However, the model just described is adequate to illustrate the main features involved in an optimal procedure of public good production and financing.

The continuous procedure summarized in equations (2.5) and (2.8) represents an extreme theoretical form for which we can guarantee that the economy will move in a continuously Pareto improving direction, but the model is very far from being applicable even in a real 3-good economy. It is important to rote the massive informational and decisionmaking demands on both the government and the consumers in order to carry out the procedure.

a. The government must have continuous perfect information about each person's marginal valuation of the public good and about the marginal productivity of the public good production function.

b. The consumers must be continually in the private goods market offering and trading in order that the market can continuously find its new equilibrium. They must also be kept continuously up to date on their latest tax assessment so that they will know how much they have to trade.

The object is to develop procedures that are more applicable, but that will retain the optimality properties of the foregoing procedure. We will continue to use the model of a 3-good economy with public good production in order to examine the general equilibrium and Pareto optimality features of the problem. (It is clear that the Pareto optimality feature of public good production cannot be dealt with in a partial equilibrium framework, even though writers often use the terminology of general welfare economics when dealing with benefit-cost in partial equilibrium analysis).

The first step toward making the procedure applicable is to discretize the decision steps, since no real world decision procedure in economics can be carried out in a truly continuous fashion. In order to focus on the problems that are strictly associated with the discreteness of the procedure we will retain the assumption that the government has perfectly knowledge of people's valuations.

The use of a discrete decision procedure requires some additional definitions as follows. Beginning at some economy equilibrium $[p,(x_i),z]$, the government must decide on some discrete increment q in the public good that it will propose for production. Once the ocnsumers are informed of the proposal q they can form their own valuations of q in one of several ways whose merits will be discussed below.

Since good 1 is used for input into the production of any changes in z we will state all valuation in units of good 1.

C.V. Measure of Valuation

One of the most common ways of measuring person i's valuation of the proposed increment of the public good is to determine the maximum amount of good 1 he would be willing to give up in order to have the increment q produced. This measure is called (in certain contexts) the compensating variation (CV) associated with increment q. However, CV is usually defined in terms of a fixed nominal income and known prices, therefore it does not lend itself well to use in a general equilibrium context [see K-G. Maler, p. 126]. Under two different assumptions we consider the following CV measures.

Fixed Price Assumption

$$\nu_i^p = [\Delta x_{i1} | h_i(\hat{x}_{i1}-\Delta x_{i1},\hat{x}_{i2},z+q,p_1,p_2) = h_i(\hat{x}_{i1},\hat{x}_{i2},z,p_1,p_2)] \quad (2.9)$$

where h_i is the maximum utility function:

$$h_i(\omega_1,\omega_2,z,p_1,p_2) = \max \ u^i(x_{i1},x_{i2},z)$$
$$\text{s.t. } p_1x_{i1} + p_2x_{i2} = p_1\omega_1 + p_2\omega_2. \qquad (2.10)$$

ν_i^p measures the maximum amount of good 1 that person i would be willing to give up if he knew that after the increment q were produced he would be able to trade in the private goods market at the current prices p_1 and p_2. The problem with this measure is that the prices at which he will be able to trade after q is produced (if indeed it is produced) are not known at the time when γ_i^p is needed. By using current prices as the ones he will be able to trade at, he may overstate his valuation and end up at a utility level that is lower than his present level. This would destroy the Pareto-improving property of the allocation procedure. One way of avoiding this is to use the following conservative approach.

Fixed Utility Assumption

$$\nu_i^U = [\Delta x_{i1} \ u^i(\hat{x}_{i1}-\Delta x_{i1},\hat{x}_{i2},z+q) = u^i(\hat{x}_{i1},\hat{x}_{i2},z)] \qquad (2.11)$$

This measure assumes that the consumer will not be allowed to trade after he is taxed and the project is produced. Of course, if later he is able to trade then he will only do so if he is able to move to a preferred position. Therefore this method can never overstate the person's valuation of q, but it car. understate the true valuation. An allocation procedure that is based on this measure will move only to Pareto superior points, but it may fail to move to some points that are Pareto superior.

E.V. Measure of Valuation

A frequently discussed measure of public good valuation is the minimum amount that a consumer would have to be given to make him as happy as he would be if he had the increment in the public good. The two EV measures that correspond to the CV measures given above are:

$$\mu_i^p = [\Delta x_{i1} \ h_i(\hat{x}_{i1}+\Delta x_{i1},\hat{x}_{i2},z,p_1,p_2) = h_i(\hat{x}_{i1},\hat{x}_{i2},z+q,p_1,p_2)]$$

$$\mu_i^U = [\Delta x_{i1} \ u^i(\hat{x}_{i1}+\Delta x_{i1},\hat{x}_{i2},z) = u^i(\hat{x}_{i1},\hat{x}_{i2},z+q)] \qquad (2.13)$$

Although the EV measures may have some theoretical interest in a partial equilibrium framework, it is clear from the expressions (2.12) and (2.13) above that they are not relevant to the type of public good allocation decision under consideration here. In order for the government to know whether to produce the increment q, it needs to know if the required resources for that production can be obtained without making someone worse-off. The difficulty with the EV measures is that they ask the consumers to compare two allocations that are technologically infeasible. The two allocations, as seen in (2.12) and (2.13) are $[(x_{i1}+\Delta x_{i1},x_{i2}),z]$ and $[(\hat{x}_{i1},\hat{x}_{i2}),z+q]$. It is clear that if the competitive allocation $[(\hat{x}_{i1},\hat{x}_{i2}),z]$ is both feasible and efficient, then the two allocations compared in the EV measure are either infeasible or inefficient except when $\Delta x_{i1}=0$, for all i, and when q=0. This fact renders the EV measures useless for decisionmaking in a general equilibrium context. Therefore we will use only CV measures in the following procedures.

Using one of the CV measures of valuation of the proposed increment q in the public good, the government decision procedure in the discrete framework is described below.

The <u>marginal social valuation</u> of the public good in the discrete case is:

$$V(z,q) = \sum_i \nu_i \tag{2.14}$$

The <u>marginal social cost</u> associated with a change from z to z+q of the public good is:

$$\Delta C = C(z+q) - C(z) \tag{2.15}$$

Therefore the <u>net marginal social valuation</u> is $[V(z,q) - \Delta C]$, and the government's decision rule will be to produce the increment q if $[V(z,q) - \Delta C] > 0$, and to not produce it otherwise. If it is to be produced then the necessary resources ΔC of good 1 are collected from the consumers according to the following formula:

$$\Delta s_i = \nu_i - \gamma_i[V(z,q) - \Delta C] \tag{2.16}$$

where Δs_i denotes the discrete change in person i's total tax and γ_i is person i's share of the net surplus, where $\sum_i \gamma_i = 1$ and $\gamma_i > 0$, i = 1, . . .,I. Summing the tax changes over all consumers we see that:

$$\sum_i \Delta s_i = \Delta C \tag{2.17}$$

which is the needed amount of good 1 for input to produce the increment q.

<u>Features of the Discrete Decision Process</u>

Once the government has chosen which valuation measure to use, the process just described can be applied, and it is clearly more applicable than the previous continuous procedure since it will need only a finite amount of information for each proposed incremental change in the public good. The method works equally well for proposals where q < 0, therefore it can also be used to consider reductions in the public good level. Unfortunately the method has several weaknesses that detract somewhat from its greater degree of applicability. They are:

a. The procedure will, in general, stop before reaching a Pareto optimum, for any given q.

b. The procedure may cause reallocations that will make some consumers worse-off if the valuation measure ν^p is used. Therefore the procedure would not be Pareto-improving.

Both of these weaknesses can be eliminated through modification of the procedure, however, the modifications reduce the applicability by increasing the informational demands.

Problem (a) can be resolved by changing the size or the sign of q whenever a stop is encountered. As q becomes smaller the procedure requires more information per unit change in the public good, however, the government could make some judgment about how close is "close enough" to a Pareto optimum, in view of the cost of information for each decision.

Problem (b) can be eliminated by using ν^U rather than ν^P as the valuation measure. The difficulty with using ν^U, as mentioned earlier, is that it systematically understates the person's true valuation of the public good, given that there will be some trading possibilities in private goods if the project is approved. The valuation measure ν^U is based on the assumption that the consumers will not engage in private goods trade after the public good decision. To guarantee that the understatement is not preventing the detection of a possible Pareto improving move, the size of q must be reduced whenever a stop is encountered in order to see if there remain any possible Pareto improvements. The reduction in q increases the information requirements of the procedure.

A separate approach to this problem is to attempt to get accurate estimates of what the equilibrium prices will be if the size q proposal is approved. This is a difficult task since the prices will depend on market interactions that cannot be theoretically calculated without knowing all consumers' utility functions. Such information is equal in order of magnitude to that required in the continuous procedure. However, if rather than doing theoretical calculations of prices we allow a contingent claims market to operate then each consumer not only gets an accurate estimate of the future prices if the project is approved but he is able to hedge completely against possible loss due to price changes. The claims would be on private goods and they would be contingent on the approval of the increment q. Each person would have $(x_{i1}-\nu_i, x_{i2})$ units of contingent goods 1 and 2 to trade with, and would alter their valuations ν_i as the contingent goods market moved toward equilibrium. Once the contingent goods market reached an equilibrium the government could use the already described decision criteria to make the project approval and taxation decisions. The procedure would be guaranteed to move only to a Pareto superior allocation. If the project were not approved then the contingent claims would not be binding. Although this method requires the functioning of a competitive market for contingent claims, it uses an essentially decentralized procedure to determine accurate price estimates. It will be seen later that this type of contingent market can be very useful in applied procedures where the public good project is relatively large.

So far we have assumed that the government is able to get the consumers to reveal their correct valuations of public good changes. Unfortunately, whenever the consumers understand how their individual valuations are to be used for taxation purposes they have incentive to misrepresent their true valuations. This problem is widely referred to as the "free-rider" problem, and until recently it was thought to be unavoidable even in a purely theoretical model of an economy with public goods. Recent research has shown that it is possible to provide the proper incentives for individuals to submit accurate messages to the government concerning their true valuation functions.[3/] This work is extremely important for theoretical development in this area, however, it is very far from a form that is applicable to actual public goods decision problems.

A different approach that also pays close attention to the individuals' incentives is one developed by Vernon Smith and tested by him and others in many experimental situations involving collective decisions.[4/] This approach is not so fully developed theoretically, but it currently offers more promise in terms of application to public goods allocation problems in both a partial and a general economy framework. The method uses a system of bidding to overcome some of the distortionary effects of the free-rider problem.

In the following section we develop an extension of Vernon Smith's bidding mechanism that can be used to make Pareto improving decisions concerning public goods production in a general economy framework. The important thing about this method is that it does not require that the government know the consumers' preferences.

A Bidding Mechanism for Public Goods Decisions

In this section we develop an extension of Vernon Smith's Auction Mechanism for public good decisions to a general economy framework where private goods are traded in competitive markets, and the public good is produced by the government using private good inputs.

The bidding procedure developed here incorporates a market for contingent claims on private goods in order to avoid the type of unanticipated price changes that are associated with movements from one equilibrium to another. The claims are contingent on the approval of the public good project. Gambling on the outcome of the bidding procedure (by trading current goods for contingent claims) is prohibited since that would tend to bias people's bids and possibly cause some people to be worse off after the project decision. By trading in the contingent claims market each individual is able to determine the full value of his maximum willingness to pay for the public goods, and he can then form his bids in the same manner as in the partial equilibrium auction mechanism of Vernon Smith.

In Section 2.1 we examine the individual incentives in a partial equilibrium bidding procedure used to approve and finance a public good project. This procedure modifies Vernon Smith's Auction Mechanism[5/] by: (1) adding an initial non-binding round of bidding used to determine if bidding should continue and to provide the group with an estimate of the net project surplus; and (2) including a positive and increasing stop-probability to induce the members to avoid a stalling strategy. Without analyzing all of the possible strategies that individuals could use we look at the type and the strength of the incentives that pull the group toward (or away from) a cooperative solution that is Pareto superior to the initial position. Section 2.2 develops the bidding procedure for an economy with two private goods and one public good. The public good is produced by the government using private good inputs obtained from consumers. The nature of the price uncertainty problem and its adverse effect on bidding decisions is explained. A market for contingent claims is designed to clear simultaneously with the bidding rounds in order to overcome the problems caused by price uncertainty. Section 2.3 gives the summary and concluding remarks.

2.1 Partial Equilibrium Procedure

The purpose of the bidding procedure described in this section is to provide a framework within which a group can decide whether to approve the production of a given amount of a public good. The framework is based on the Auction Mechanism used in Smith for experiments in public good decisions.

The bidding procedure should enable the group to jointly approve and finance the production of public good projects that have a positive net surplus and to reject projects that do not. The procedure should not lead anyone into the position of being worse off after the decision, and it should provide the incentive and guidelines for quickly arriving at a cooperative Pareto superior solution when one exists. Although we will deal here with only a single discrete decision, it is clear that by using a sequence of such decisions the group could move toward a Pareto optimum.

Individual group members indicate their support for (opposition to) a project by submitting anonymous positive (negative) bids which establish the maximum amounts they can be assessed if the project is approved. Project approval occurs when the sum of the bids is at least as great as the project cost.

The total project cost is known to all, and after each round of bidding the sum of the bids is announced. As long as an individual's own project valuation is greater than his bid, he favors approval of the project. There are a finite number of bidding rounds, and if the project is not approved by the last round then it is judged infeasible and is abandoned. All potential gains from the project are lost if it is not approved by the last round. Members are not allowed individually to purchase small amounts of the public good.

If each person never bids higher than his true valuation then the method will never approve a project that makes anyone worse off, and in particular will not approve a project with a negative net social valuation. The procedure should then be considered successful if it is able to arrive at cooperative approval of projects having positive net valuations more frequently than other methods of unanimous social choice. Such a comparison can be made using experimental methods,6/ but cannot be done theoretically.

The fact that there is incentive for each member to keep his bid low in the hope that others will fill in the gap and cause the project to be approved may make it appear that this procedure has not really avoided the classic "free-rider" problem, and of course it hasn't entirely. However, it is important to recognize that the problem is greatly changed and is diminished in strength in this framework. In a contingent bidding procedure (one where bids are contingent on project acceptance) each person knows the amount of public good to be produced if his bid is accepted. Therefore he knows exactly what it is that he is valuing when he forms his bid. The same thing is not true in the case of private uncoordinated purchases of a public good or under systems of uncontingent donations toward production of a public good. As long as the sum of bids is less than the project cost, the incentive to free ride is offset by the incentive to increase the sum toward project approval. The strength of this incentive is diminished as one's bid gets close to his own project valuation. In the bidding procedure each person knows that he can signal a willingness to support the project without the fear that he will be left "holding the bag" if others don't cooperate sufficiently. Also the addition of bids for the same project corresponds to the way in which valuations must be added to determine the group value of a public good.

These features all tend to diminish the strength of the "free-rider" effect within this context. The results that Vernon Smith has obtained in experimental studies of his Auction Mechanism for public good decisions indicate that the free-rider effect is indeed diminished in such a context. The following modified auction mechanism was designed after observing the results of experiments conducted by Smith.

Project Approval

Consider a group of N individuals, indexed $i = 1, \ldots, N$, who will all be affected by the production of a public good project costing C. Person i has true valuation V^i for the proposed project. The following bidding procedure will be followed to determine if the project will be constructed and how much each person must pay toward the total cost C. There will be two stages of bidding composed of a total of T+1 rounds of bids. There will be only one round of bidding in Stage I. The purpose of this round of bidding is to determine whether or not the project will be considered further and to give everyone an estimate of the net project surplus, therefore the bids will be non-binding in terms of tax purposes.7/

Stage I (The Non-Binding Bids)

Each person anonymously submits his initial bid b_0^i. The decision rule for Stage I is: If $\sum_i b_0^i < C$, then stop bidding and abandon the project. If If $\sum_i b_0^i > C$, then proceed to Stage II.

The purpose of Stage II is to decide on individual payments that will cover the total cost of the project. Each person determines his own bid of offered support for the project knowing that if the total of the bids is not high enough then the project may fail.

Stage II (The Binding Bids)

There will be at least one and at most T rounds of bidding in this stage. After each round in which the total bids fall short of cost there is a known probability that the procedure will be stopped and the project abandoned. The probability of this type of stop is t/T, where t = 1, . . .,T is the number of the round. The purpose of this increasing "stop" probability is to provide the incentive to the group to move quickly toward a solution.8/ At round t = 1, . . .,T the decision procedure will be:

If $\sum_i b_t^i > C$, then stop bidding, tax each member $b_t^i - 1/N(\sum_i b_t^i - C)$, and produce the public good.

If $\sum_i b_t^i \leq C$ and $\theta_t = 1$, then post the value $\sum_i b_t^i$ and proceed to the next round.

If $\sum_i b_t^i \leq C$ and $\theta_t = 0$, then stop bidding and do not produce the public good.

The distribution of θ_t is: $P(\theta_t = 0) = t/T$, t = 1, . . .,T and

$$P(\theta_t = 1) = 1 - P(\theta_t = 0)$$

The complete bidding procedure is explained to each member before round 0 of bidding.

There is no attempt made here to model completely the behavior or strategy of each individual. However, by looking at the situation from the point-of-view of a single agent we can get some idea of the incentive structure facing him. I will argue here that each person references his behavior to a commonly held notion of "fairness" which in this situation is defined as an equal sharing of the apparent gains. A person does not always feel obliged to abide by exact "fairness," and will at times attempt to get more than his "fair" share, and at other times be willing to accept less than his "fair" share in order to prevent the failure of the project.

Person i's true valuation of the public good is V^i. During Stage I of the bidding process he can bid any arbitrary value since he knows that he is not accountable for his bid in terms of future taxes, and no one else will ever know the value of his initial bid. However, he has incentive to make his initial bid close to his true valuation V^i. The reason for this is that if he overbids (i.e., bids $b_0^i > V^i$) in an attempt to help carry the project into Stage II then he is contributing to the overstatement of the apparent consumer surplus $(\sum_i b_0^i - C)$ associated with the project. An overstated apparent surplus will make it difficult to obtain joint approval in Stage II even if there is a large real surplus since unless he makes his Stage II bids greater than V^i (which would be foolish) then the other members must absorb his initial overbid believing that they are getting less than their fair share. On the other hand, if person i bids $b_0^i < V^i$ in an attempt to understate the apparent surplus so that he can get a larger share of the true surplus when the project is approved he increases the likelihood that the project will fail in round 0. Now it is certainly true that there may be some overbidding in Stage I for various possible reasons, however, if there are strong tendencies in one direction then this will result in a high proportion of failures in either Stage I or Stage II of the process. This high failure rate would presumably provide the incentive to correct this type of misbidding.

In Stage II person i is aware of the total apparent surplus $(\sum_i b_0^i - C)$ established in Stage I. If he takes this number as being the true surplus then his fair share is $1/N(\sum_i b_0^i - C)$ and his corresponding fair bid is $b_*^i = b_0^i - 1/N(\sum_i b_0^i - C)$. He knows that if everyone bids his fair bid that the project will be exactly approved on the first round and each will obtain an equal share of the apparent surplus. However, he may bid higher or lower than his fair bid depending on how urgently he wants the project approved and on what he believes that others will do. In general if he bids higher then he is contributing to rapid project approval, and if he bids lower he is attempting to get a larger share of the surplus while some socially beneficial projects will fail.

It was mentioned earlier that the procedure is designed to enlist everyone's support by giving each person a vested interest in the approval of the project. There is, of course, the possibility that one of the members derives his pleasure from foiling the plans of the others. There is no way that the procedure can offset this type of behavior if the person is determined to foil every project. Whether or not this type of behavior is frequent enough to cause problems for the method would most likely be brought out in experimental studies.

Project Size and Approval Determination

The two-stage bidding procedure can be extended to a procedure that determines both the size and approval of the public good project. This procedure takes advantage of the incentives present during the first stage to obtain information about the group valuation function of the public good.

Suppose that each of I members has the individual valuation function $V^i(Z)$, where $Z \geq 0$ is the level of the public good. Suppose that C(Z) is the total cost of Z units of the public good. For convenience we assume that V^i is concave with $V^i(0) = 0$, for all i, and that C is convex and increasing with $C(0) = 0$.

Stage I

Each member anonymously submits a bid function $b_0^i(Z)$ knowing that the aggregate function $\sum_i b_0^i(Z) - C(Z)$ will be used to determine the project size to be considered for approval in Stage II. The project size $\bar{Z}$ is selected to maximize $\sum_i b_0^i(Z) - C(Z)$, and $\bar{Z}$, $\sum_i b_0^i(\bar{Z})$ and $C(\bar{Z})$ are announced to all members.

Stage II

This stage is handled exactly as in the previous procedure where $\bar{Z}$ = the project size, $\sum_i b_0^i(\bar{Z}) = \sum_i b_0^i$, and $C(\bar{Z}) = C$.

The interesting question here is whether there is incentive for the individual members to misrepresent their valuation functions $V^i(Z)$ in their Stage I bid functions $b_0^i(Z)$. The incentive for making one's initial bid function very close to one's true valuation function is the same as before, however in this case since the person cannot know what project size will be selected he is induced to bid "honestly" over the whole range. He wants the project to succeed in Stage I (i.e., to have the selected project to be $Z \neq 0$). but does not want the apparent surplus to be inflated so that approval is more difficult in Stage II.

2.7 Bidding Procedure for a General Economy

All of the previous sections rested on the assumption that people's valuations of a public good do not change as a result of the production of the public good. We assumed that the valuations were in units of money that the person is willing to give up to obtain the public good and that only money is required for the production of the public good. Of course, in reality, the production of a public good requires real resources which when demanded as inputs into public good production may affect the prices of all other goods. These price changes will alter both the money valuation and the real valuation of the public good, therefore raising some serious doubts about decision criteria that assume no changes take place. The difficulties are caused by the fact that changes in the level of the public good are associated with a movement from one general equilibrium to another, but at the time that agents are expected to make bids on such a change they do not know the prices that will prevail in the new equilibrium. Therefore, they are unable to know their own maximum willingness to pay for the proposed public good, and consequently they have inadequate basis for bidding. The following bidding procecure incorporates a market for claims that are contingent on project approval to provide the type of information needed by each agent. This contingent claims market allows the group to get close to the full valuation of the proposed public good and it protects each agent from ending up worse off after project approval due to unanticipated price changes. Therefore, by using this method the group will be more likely to find a Pareto superior solution if one exists since the element of price uncertainty will be removed, and we can be assured that projects will only be approved if they lead to Pareto superior allocations. The method uses the incentive structure of the previous section to induce members toward a cooperative decision. We will consider only the problem of project approval.

General Equilibrium Method

Consider an economy with two private goods and one public good. The public good is produced by the government using inputs of private good 1 obtained from the consumers. There are N consumers, indexed i = 1, . . .,N, who each have a utility function $u^i(x^i,z)$, where x^i is the consumer's vector of private goods and z is the amount of public good. The economy's initial resources of private goods is $\omega = \binom{\omega 1}{\omega 2}$, and there is initially no public good. The public good production function is z = f(y), where y is the input of private good 1. There is no production of private goods, so the economy resource constraint is given by $\sum_i x^i + \binom{y}{0} \leq \omega$.

The public choice problem faced by this economy is whether to produce z units of the public good and if so how to distribute the taxes among the consumers to obtain the needed input. The total input of good 1 that is needed to produce z is denoted $C = f^{-1}(z)$. The society wants to approve this public good project if and only if it can do so in a Pareto improving way. The economy is assumed initially to be at the competitive equilibrium $[(x^i),0,p]$, where (x^i) is the allocation of private goods among the consumers, 0 is the current amount of public good, and $p = \binom{p1}{p2}$ is the equilibrium price vector. As before there will be T+1 rounds of bidding indexed t = 0, 1, . . .,T. There will be two stages of bidding consisting of the non-binding bids in Stage II. At each round of bidding a contingent claims market will be conducted, and the bids for that round become official when the market clears. No trading of uncontingent claims (i.e., contributing to possible non-approval of the project. He is never tempted to bid higher than V^i during Stage II since if the project is approved then he will suffer a net loss.

As t gets larger and closer to T (increasing the probability of a stop) the persons whose bids are much lower than their valuations have strong incentive to raise their bids in order to increase their bids since their gains would be small even if approval is accomplished. In this way the bidding procedure tends to put the greatest individual pressure for bid increases on those who are attempting to get the largest gains. It is they who have the largest vested interests in the project's success.

Ignoring the costs associated with conducting the bidding, the process will move only to Pareto superior points. This is true because no one will make a Stage II bid that is higher than his true valuation. Therefore, we know that the process will not move if there are no longer projects having a positive net surplus. So, in this partial equilibrium sense, the process will only move toward Pareto superior points and will not move from a Pareto optimum. However, there is the possibility that even though there is positive net surplus associated with a project that it will not be approved since the procedure may stop before approval is reached. It may seem wasteful that some projects having positive consumer surplus will fail due to a stop occurring before the cooperative solution is reached. However, if we imagine a procedure where, whenever there is a positive apparent surplus in Stage I, the Stage II bidding will continue until the group arrives at a cooperative solution, then we see that there is almost no incentive for the individuals to raise their bids up toward their valuations. By using a system that may cause a loss due to non-cooperative behavior at each round we provide some disincentive for holding out for a "free ride." The cost is that claims contingent on the failure of the project is allowed during the entire bidding procedure. This rule is used to prevent speculation on the success or failure of the project which might cause some members to end up worse off than originally. At the beginning of each round of bidding person i has x^i as his initial endowment of contingent claims. His choice of contingent claims at the end of round t is denoted $\mu_t^i = \begin{pmatrix} \mu_{1t}^i \\ \mu_{2t}^i \end{pmatrix}$. The current contingent claims prices are denoted ρ_1 and ρ_2. Person i's bid in round t is denoted b_t^i, and it represents the maximum amount of good 1 that he is willing to deliver to the government upon the approval of the project.

Stage I (The Non-Binding Bid)

Stage I will consist of one round of bids used only to determine if the project should be considered further. Since the contingent claims market in this round (and in other rounds) is competitive we will first look at the decision faced by the price taking agents. Given z, ρ_1 and ρ_2, person i chooses person i chooses a bid b_0^i and a contingent claims vector μ_0^i such that:

$$u^i(\hat{\mu}_0^i, z) \geq u^i(x^i, 0) \text{ and } \quad (2.18)$$

$$\hat{\mu}_0^i \text{ maximizes } u^i(\mu_0^i, z) \quad (2.19)$$

$$\text{subject to } \rho_1\mu_{10}^i + \rho_2\mu_{20}^i \leq \rho_1(x_1^i - b_0^i) + \rho_2 x_2^i$$

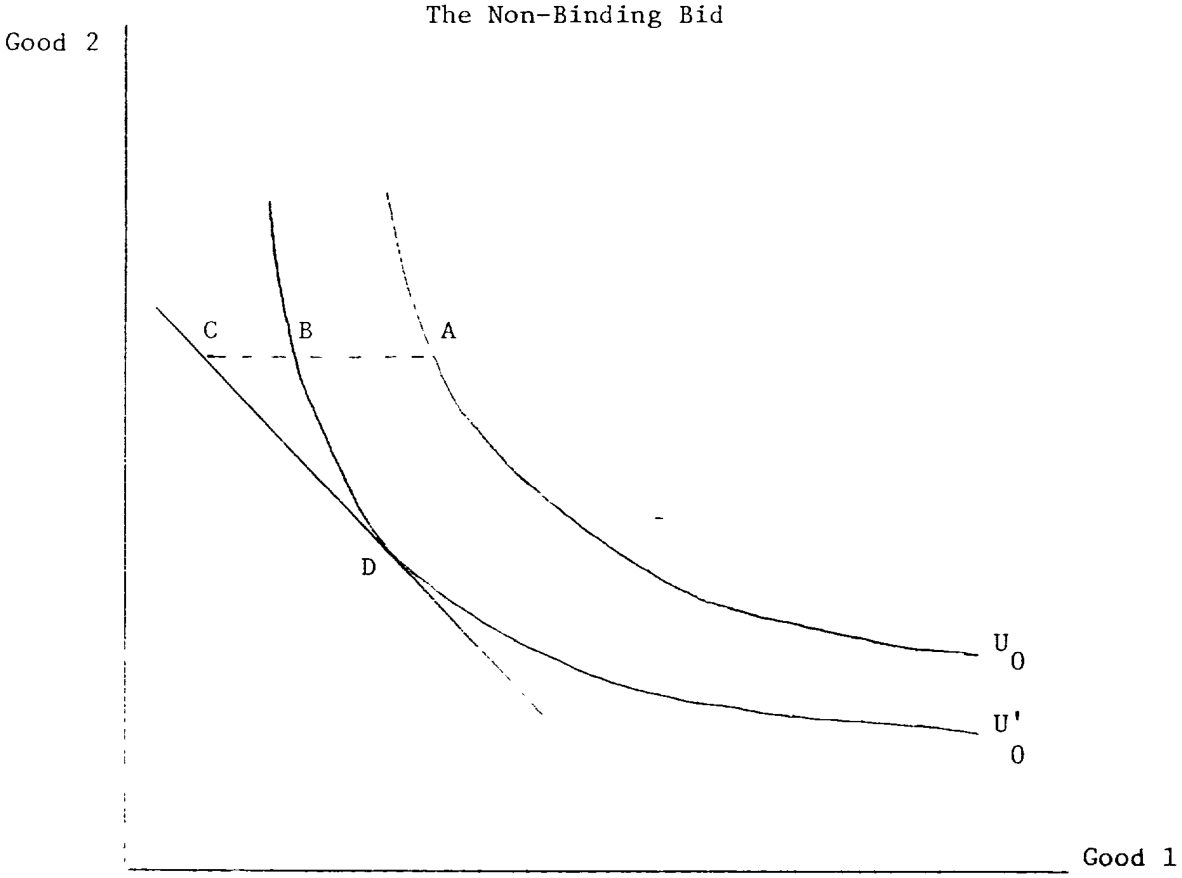
Let $\hat{b}_0^i$ denote the bid when (2.18) is an equality. Then $\hat{b}_0^i$ is the person's true maximum willingness to pay for the public good. In general, $\hat{b}_0^i$ is greater than the standard measure known as the compensating variation (CV), since the calculation of CV ignores price and trading considerations. Let q_0^i denote the compensating variation, in units of good 1, for z units of the public good. Mathematically, q_0^i satisfies the equation:

$$u^i(q_0^i, z) = u^i(x^i, 0) \quad (2.20)$$

Clearly $q_0^i \leq \hat{b}_0^i$, and except for a unique price ratio $q_0^i < \hat{b}_0^i$. This relationship is illustrated in the indifference curve diagram of Figure 2.1, where $U_0 = u^i(x^i, 0)$ denotes the. indifference curve when there is zero public good, and U_0' denotes the indifference curve at the same utility level when there are z units of public good. q_0^i is the distance BA on the diagram, and $\hat{b}_0^i$ is the distance CA. The slope of the line CD indicates the price ratio for

Figure 2.1

The Non-Binding Bid



contingent claims. Therefore, we see that the contingent claims market allows the society to determine its full social valuation of the proposed public good. whereas CV measure does not because it doesn't allow for possible private goods trading. The Stage I bids become effective when the following market clearing condition holds:

$$\sum_i \mu_0^i + \begin{pmatrix} \sum_i b_0^i \\ 0 \end{pmatrix} = \omega \qquad (2.21)$$

The decision rule for Stage I is:

If $\sum_i b_0^i \leq C$, then abandon the project.

If $\sum_i b_0^i > C$, then post the values C and $\sum_i b_0^i$, and proceed to Stage II.

As in the partial equilibrium procedure each person here has some incentive to give an honest bid on round 0 since he knows that his bid will not be used to assign his tax and he has a vested interest in Stage I approval, but he realizes that an overstated apparent surplus will cause difficulty in Stage II approval.

Stage II (The Binding Bids)

Each person knows the value of the apparent consumer surplus established during round 0, therefore they each have some idea of their own fair bid $b_*^i = b_0^i - 1/N(\sum_i b_0^i - C)$. Also, each person is aware that the "stop" probability after round t is given by t/T. During round t with given values ρ_1 and ρ_2 person i chooses b_t^i and $\hat{\mu}_t^i$ such that:

$$u^i(\hat{\mu}_t^i, z) \geq u^i(x^i, 0), \text{ and} \qquad (2.22)$$

$$\hat{\mu}_t^i \text{ maximizes } u^i(\mu^i, z) \qquad (2.23)$$

$$\text{subject to } \rho_1\mu_1^i + \rho_2\mu_2^i \leq \rho_1(x_1^i - b_t^i) + \rho_2 x_2^i$$

The bids are effective once the prices ρ_1 and ρ_2 are such that the contingent claims market clears:

$$\sum \hat{\mu}_t^i + \begin{pmatrix} \sum_i b_t^i \\ 0 \end{pmatrix} = \omega \qquad (2.24)$$

Each person will bid in such a way that (2.22) is a strict inequality. The social decision rule in round t is:

If $\sum_i b_t^i > C$, then stop bidding, tax each member and produce the public good.

If $\sum_i b_t^i \leq C$ and $\theta_t = 1$, then post the value $\sum_i b_t^i$ and proceed to the next round.

If $\sum_i b_t^i \leq C$ and $\theta_t = 0$, then stop bidding and do not produce the public good.

The. distribution of θ_t is:

$$P(\theta_t = 0) = t/T, \; t = 1, \ldots, T \text{ and}$$

$$P(\theta_t = 1) = 1 - P(\theta_t = 0).$$

This rule is exactly the same as in the partial equilibrium procedure except that here bids and the tax are in units of good 1 rather than money. If the project is approved in round t, then person j's holdings of the two goods after taxes is:

$$\begin{bmatrix} \hat{\mu}_{1t}^j + 1/N(\sum_i b_t^i - C) \\ \mu_{2t}^j \end{bmatrix}$$

This means that the contingent claims become real claims and if the sum of the bids is greater than the cost of producing z units of public good, then the households share the excess. Once the project has been approved, then the trading of private goods can resume.

It is clear from the description of the procedure that a project will only be approved if it leads to a Pareto superior allocation. Therefore, the procedure does guarantee that no one will be hurt as a result of unanticipated price changes.

Even though the general economy procedure was explained using a simple 3-good economy, it should be clear that there would be no theoretical problems involved in going to economies having n private goods, m public goods, and more general production sets for the public goods. The main feature that was introduced in order to use the partial equilibrium technique in a general economy was the market for contingent claims.

It is important to recognize the way that the contingent claims market is being used in this procedure to avoid a rather difficult problem concerning price expectations. The contingent claims market artificially creates a close approximation to the real market that will exist once the taxes are collected and the public good produced. With this market the agents are able to have accurate price expectations and therefore to accurately calculate their valuations of the public good. By prohibiting trades involving current (uncontingent) goods we avoid all of the problems caused by mixing people's preferences with their subjective probabilities that the project will be approved. Allowing only trade of contingent commodities once the project has been proposed separates the two types of markets so that gambling on the outcome of the project approval decision through trade is avoided. If this were allowed then the nature of the process would be altered considerably.

The use of contingent claims markets tends to conceal a severe problem in the applicability of the general economy procedure. We have assumed that the contingent claims market will clear simultaneously with each round of bidding without recognizing the substantial difficulty in finding the market clearing equilibrium in practice. Economists usually do not dwell on the difficulties involved in attaining the competitive equilibrium, so I will not do so here. However, in any application of this technique the problem would have to be dealt with.

2.3 Conclusions

By framing the public good decision within a general equilibrium model we are able to see clearly some of the problems associated with the use of the standard partial equilibrium techniques. Some of the features that are brought out in this framework are the following:

1. It emphasizes the fact that public good production is a reallocation process that moves the economy from one competitive equilibrium to another. This is especially important when dealing with projects that are not infinitesimal in size, since the discrete reallocation will lead to price changes that cannot automatically be anticipated. On the other hand, the partial equilibrium method views the government as a type of Marshallian firm whose actions will not have any effect on the rest of the economy.

2. The framework allows us to see clearly why the application of partial equilibrium methods of cost-benefit will not lead to allocations that are Pareto superior if the project is of discrete size.

3. The approach emphasizes the logical impossibility of separating costs from benefits and valuation from taxation and trade.

4. The inappropriateness of the EV measure for use in public goods decisions is made obvious by the technical infeasibility of the allocations it compares.

5. Changing the size of the project proposals brings out the tradeoff between information and allocative efficiency within this framework.

2.4 Recommendations

Based on the models developed in this report, there are several recommendations that can be made for avoiding the types of distortions caused by either unanticipated price changes or "the free-rider effect." They are:

1. Although it may not be practical to hold contingent markets for all commodities, it is conceivable that the government could organize markets for those goods that are highly likely to undergo substantial price changes. In the air pollution example, it would be useful to have a contingent market for real estate. Another likely candidate for contingent trading is any major input into the public good production. Thus, if the proposed project is to reduce air pollution by requiring (or prohibiting) the use of certain types of

fuels, then the government could organize contingent markets for various sources of energy among which there may be substantial substitution. The sponsorship of such markets would improve the valuation estimates of the public good project and it would allow consumers and producers to hedge against possible losses due to price uncertainty caused by the project. Furthermore, their existence would provide the means and the incentive for the public to stay informed about proposed public goods projects. The reason that the government should sponsor such markets rather than let them simply evolve due to normal market forces is to prevent the substantial danger of moral hazard that is present when people are allowed to gamble on the outcome of a decision they can influence. The government could insure that the contracts are only binding if the project is approved. The legal machinery required to enforce a contract that is contingent on a government decision would have to be developed very carefully since it is not now in existence and is not likely to develop on its own.

2. Another, less radical, suggestion for reducing the distortion caused by unanticipated price changes resulting from the public good decision is to have the government attempt to estimate the nature of important market interactions in supply and demand in order to calculate adjustments to the valuation and cost figures that are based on current prices. Econometric models for this type of estimation require more information than those used to estimate single supply or demand functions, however such techniques are currently in wide use and could be easily applied to this type of scheme.

3. The difficulty involved in applying the bidding mechanism to a real public good proposal depends on the exact nature of the public good. It is important in any application of this technique that the participant bidders realize the exact nature of the proposal, the current total of bids, and the fact that their own bid will be a binding obligation. If it is simply a number which they know will have no relationship to their tax, then it cannot provide a measure of their true valuation.

FOOTNOTES: CHAPTER II

1/ See Milleron for a survey to this literature.

2/ See Champsaur and Malinvaud for procedures for allocating public goods in a planned economy.

3/ See Groves and Ledyard for this result in a general equilibrium framework, and see Clarke, Groves and Loeb, and Tideman and Tullock for the result in partial equilibrium models.

4/ See Bohm, Ferejohn and Noll, Scherr and Babb, and Smith for descriptions and results of these experiments.

5/ Reported in Smith.

6/ It is clear that as the positive net surplus becomes smaller that there is less incentive for the members to cooperate. In experiments we could measure the approval rate as a function of the net surplus in order to determine how effective the method is.

7/ The usefulness of an initial round of non-binding bids is shown clearly by the experimental results reported in Smith. He designed this trial as a "practice trial" used to provide familiarity with the procedure but noted that it also provided the subjects with valuable information about the potential surplus available. I have made the continuation of the bidding contingent on obtaining a positive net surplus in the initial trial in order to provide disincentive to underbidding here.

8/ It is apparent in some of the experimental results reported in Smith that the bidding didn't get serious until the process got close to the last trial. Incorporating an increasing random stop probability makes each of the stage II rounds a potential last round. This should increase the seriousness of the bidding very early in the procedure.

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CHAPTER III

THE VALUE OF LEARNING ABOUT CONSUMPTION HAZARDS

by
Robert A. Jones

This report examines the implications of reducing uncertainty about the hazards associated with various forms of consumption. Section 3.1 focuses on the determinants of the dollar valuation of such a reduction in uncertainty, measured as the willingness to pay. The chapter begins with the simplest 'Marshallian' case and then successively generalizes the results at the cost of making Taylor's series approximations. It is shown that the value of reducing uncertainty is readily determined once estimates have been made of the ex-post shifts in demand associated with the information.

A major simplifying feature of the models in Section 3.1 is that all prices are exogenous. While this is perhaps a reasonable first approximation for many applications, it is surely inappropriate for non-produced commodities of uncertain quality. One important case is the adjustment of land prices to reflect differences in air quality in an urban environment. This case is the primary focus of Section 3.6. First the equilibrium location of a population with different incomes is described. It is shown that there is only a mild presumption in favor of location in the less hazardous areas by the more wealth. Optimal location of an identical population is then examined. Finally, it is shown that the expected value of research which reduces uncertainty about an environmental hazard may be fully reflected in land values.

Section 3.11 introduces time into the analysis, taking account of the fact that the prospect of future information will affect consumption decisions made prior to the receipt of the information. The central result is that if the possibly harmful effects of consuming a particular good depend on its accumulated consumption over the lifetime, then the prospect of receiving information about the maximum safe level of consumption reduces current consumption of that good.

3.1 The Value of Information

If a consumer is uncertain about the value of some parameter, for example the 'quality' of a particular product or the probability it will result in early death, he will in general be willing to pay to obtain a better estimate of the unknown parameter. In the following section we ask how much a consumer would be willing to pay for perfect information.

Formally, suppose uncertainty is captured by a parameter s and the utility of the consumer in state s is:

$$u = u(x(s);s) \tag{3.1}$$

where $x(s) = (x_1(s),...,x_n(s))$ is consumption in state s.

To focus upon uncertainty about the quality of a product we assume that neither the price vector p nor income M are state dependent. Then with perfect information about the state provided at a cost of V, the consumer chooses x(s) to maximize u subject to his budget constraint. That is x(s) yields the solution of:

$$u(s) = \underset{x}{\mathrm{Max}}\{u(x;s)\,|\,p'x \leq M - V\}. \tag{3.2}$$

Since the cost of obtaining the information is incurred prior to knowing the true state, anticipated benefit is a random variable u(s). Assuming that the consumer's preferences satisfy the von Neumann-Morgenstern axioms we can express the benefit as the expectation of this random variable, that is:

$$\begin{aligned} U^*(V) &= \underset{s}{E}u(s) \\ &= \int_{s \varepsilon S} u(s)dF(s) \end{aligned} \tag{3.3}$$

where F(s) is the consumer's subjective probability distribution over the set of feasible states S.

Without the information, the consumer simply chooses x^o to maximize his expected utility. That is x^o yields the solution of:

$$U^o = \underset{x}{\mathrm{Max}}\{\underset{s}{E}u(x;s)\,|\,p'x \leq M\} \tag{3.4}$$

Since x^o is a feasible solution to problem (3.3)when V = 0, $U^*(V) \geq U^o$ at v = 0. Moreover U*(V) is a non-increasing function of V. Therefore for some V* the expected utility associated with being perfectly informed at the time of purchase is equal to the expected utility in the absence of this information. V* is therefore the most the consumer would be willing to pay to be perfectly informed. That is, V* is the <u>reservation price</u> or <u>value</u> of perfect information.

In the following sections we derive expressions for V* under alternative assumptions about the utility function u(x;s). Section 3.2 considers the simple Marshallian case in which the marginal utility of expenditure on other goods is constant and independent of the state. This generates a particularly simple expression for the value of information. Section 3.3 introduces the more plausible situation in which marginal utility varies. After obtaining an expression for V* using the logarithmic utility function, a first order approximation is derived. The accuracy of this approximation is then discussed.

In Section 3.4 a first order approximation of the value of being perfectly informed is obtained for a general utility function u(x;s). The results are related to those of the previous two sections and several other special cases are then considered.

Finally, in Section 3.5 we turn to the value of becomming better informed rather than perfectly informed. A general definition of better information is provided and the first order approximation developed in section 1.3 is then extended.

3.2 Marshallian Analysis

Beginning with the simplest possible case suppost the utility associated with the consumption bundle x can be expressed as:

$$u(x_1,x_2,\dots,x_n,s) = u_1(x_1;s) + y \tag{3.5}$$

where $y = \sum^n_2 p_i x_i$ is expenditure on other goods. Suppose further that S = {1, 2}, that is, s takes on two possible values with probabilities π_1 and π_2. Then expected utility:

$$U = \pi_1 u_1(x_1;1) + \pi_2 u_1(x_1;2) \tag{3.6}$$

The consumer faces a budget constraint:

$$p_1 x_1 + y = I$$

Since we are only dealing with uncertainty about the value of a single commodity we drop subscripts on x_1, p_1, and $u_1(x_1;s)$. Substituting for y in (3.5)we have:

$$U = \{\pi_1 u(x;1) + \pi_2 u(x,2)\} - px + M \tag{3.7}$$

Then the consumer chooses $x^o(p)$ to maximize (3.7).

At an interior option we therefore have:

$$\pi_1 \frac{\partial u}{\partial x}(x;1) + \pi_2 \frac{\partial u}{\partial x}(x;2) = p \tag{3.8}$$

Interpreting this in Marshallian terms, the function $p^o(x)$ defined by(3.8)is the price that would generate a demand of x.

Compare this with decisionmaking when the state of the world is known prior to trading:

$$u_s = u(x;s) - px + M - V$$

At an interior option

$$\frac{\partial u}{\partial x}(x,s) = p \tag{3.9}$$

Therefore the function $p^s(x) = \frac{\partial u}{\partial x}(x,s)$ is the perfect information Marshallian demand curves. These are depicted in Figure 1 for s = 1 and s = 2. Note that the incomplete information demand curve:

$$p^o(x) = \Sigma \pi_s p^s(s)$$

is simply a probability weighted average of the perfect information demand curves. With full information the consumer chooses either x^1 or x^2 at the prive p. With imperfect information the consumer chooses x^o where from (3.8)

$$p^o(x^o) = \Sigma \pi_s p^s(x^o) = p$$

In the latter case expected utility is, from (3.7).

$$U^o = \sum_s \pi_s (u(x^o;s) - px^o) + M$$

$$= \sum_s \pi_s (\int_0^{x^o} \frac{\partial u}{\partial x}(q;s)dq - px^o) + M$$

$$= \sum_s \pi_s \int_0^{x^o} (p^s(q) - p)dq + M$$

If the true state is known to be s utility is:

$$\int_0^s (p^s(q) - p)dq + M - V$$

Thus the expected utility with perfect information prior to trading is:

$$U^* = \sum_s \pi_s \int_0^{x^s} (p^s(q) - p)dq + M - V$$

Choosing V* so that U^o and U* are equal we have finally

$$V^* = \sum_s \pi_s \int_{x^o}^{x^s} (p^s(q) - p)dq \qquad (3.10)$$

For the two state case depicted in Figure 3.1, this can be rewritten as:

$$V^* = \pi_1 \int_{x^o}^{x^1} (p'(q) - p)dq + \pi_2 \int_{x^2}^{x^o} (p - p^2(q))dq$$

$$= \pi_1 (\text{AREA ABC}) + \pi_2 (\text{AREA ADE})$$

The value of perfect information is then equal to the expected net increase in consumer surplus.

Returning to the S state case, suppose we approximate the demand curves $p^s(x)$ by <u>parallel</u> linear demand curves of shape

$$\frac{dp^o(x^o)}{dx} = \sum \pi_s \frac{dp^s(x^o)}{dx}$$

Substituting into (3.10)we then have

$$V^* \simeq \frac{\frac{1}{2} \sum \pi_s [p^s(x^o) - p^o(x^o)]^2}{\left|\frac{dp^o}{dx}\right|} \qquad (3.11)$$

$$= \mathrm{var}[p^s(x^o)]/2\left|\frac{dp^o(x^o)}{dx}\right|$$