Auctions

Caltech social scientists recently turned their attention to a traditional problem of all universities — how to decide which students deserve scholarships. Forty merit scholarships to allocate among 150 Caltech undergraduate applicants — this is the annual chore faced by the faculty committee on financial aid to undergraduate students. Usually the task takes several days and is characterized by much wrangling and dissension before the "top 40" candidates are agreed on. Last spring the eight-member committee arrived at agreement in three and a half hours. They did it by auction.

Forrest D. Nelson, assistant professor of economics and chairman of the faculty committee on financial aid, designed this new procedure for the committee by adapting work done by Caltech social scientists John Ferejohn, Robert Forsythe, and Roger Noll on auction-like procedures for group decision making. The problem they have been examining is the situation in which a group must select simultaneously several alternatives from among a large set of possibilities.

Although most organizational decision problems have not been traditionally viewed as economic "markets," market mechanisms can be used to provide some elegant solutions to non-economic problems. The principles that are known to govern the behavior of markets are being applied to the design of new methods for processing information and making choices in the presence of conflicting opinions. The faculty financial aid committee's task is one such case.

An "auction" of scholarship candidates may be unique, but most people have some familiarity with more usual types of auctions — art works, stamps, coins, estate sales, for example, though they may not realize that there are different kinds of auctions. In the Dutch or "descending bid" auction the auctioneer starts with a high price and lowers it in increments until someone accepts the price. The more familiar English auction uses an "ascending bid" procedure. These are both oral auctions. There are also sealed-bid auctions, in which none of the bidders knows the bids of competitors.

Whatever the procedure, an auction is a mechanism for making decisions about the allocation of resources on the basis of bids submitted by individual participants in the process. Economists and other social scientists are interested in auctions because allocation of resources is what economic and political processes are all about, and auctions seem to be an efficient, widely applicable mechanism which exhibits consistent "law-like" behavior. The basic research question is how the design of the auction — the "rules of the game" — affects the outcome of the process.

Probably the biggest auctioneer in this country is not Sotheby Parke Bernet, but the federal government. Among the government's sales activities is the Treasury Department's quarterly customs auction, in which goods confiscated for failure to pay import taxes are sold to the public. These goods, mostly liquor and wine, are not sold individually but are broken up into packages, or bundles, of approximately 20 bottles worth between $100 and $200. Since the bottles in each lot often have no relation to each other, you can find a bottle of Chateau Latour '59 packaged with a bottle of rotgut. The customs auction provides a simple, easy to research example; goods are prohibited from being resold by buyers, and retail prices can be easily checked to determine the actual market value of the bun-

dles. The sale is conducted as an oral auction with no set minimum bid. Graduate student Thomas Palfrey is studying the basic theory of this auction, addressing the general problem of why sellers want to bundle their goods this way rather than sell them individually or in homogeneous bundles (for example, a case of one particular wine). Do they make more money with heterogeneous bundles? Obviously, they think they do, but if so, why?

Palfrey's preliminary results indicate that the Customs Office is indeed acting in the taxpayer's best interests — in an auction with no set minimum the seller *does* earn more by bundling goods. The buyer in this case is at a greater advantage if goods are sold separately (perhaps because a person is more likely to have more information on the true value of a single item than of many unrelated goods in a package). However, if the auction requires a minimum bid, the opposite is generally true: The seller prefers to sell separately, and the buyers are better off with bundles, although there can be individual cases when the buyer also prefers separate items.

Other goods, besides wine, can be auctioned in bundles. Motion pictures have often been leased to theaters in this way. Palfrey was originally motivated to study bundling by his interest in government auctions for oil leases. The leases are sold by separate, simultaneous auctions for large numbers of one-square-mile tracts. The auctions are subject to a minimum bid requirement, and, as Palfrey's work predicts, the oil companies would prefer to bid on the leases in bundles.

Before bidding on the tracts — a process in which they compete — the oil companies cooperate in collecting information, and afterward also work collectively in exploiting the oil fields. The competitive market (the auction) is sandwiched between stages of nonmarket cooperation, all for the purpose of producing products that are also sold in competitive markets. Professor of Economics Roger Noll and graduate student Mark Isaac are particularly interested in the first stage — how the oil companies gather information about the tracts' potential for oil before they bid. There are rules and regulations about this: Some kinds of information may be kept by the company that produces it, while other kinds must be made available to others on a cost-sharing basis. And the government provides a lot of free information — such as that from the proposed Stereosat satellite, which will provide topographic mappings that may be useful in indicating where to explore for oil.

Isaac is exploring the issue of whether more information is necessarily good, and whether existing rules provide incentives to acquire the most efficient amount and kinds of data. He has shown that in some cases, free information will actually provide the wrong kind of incentives to the oil companies, promoting excessive competition in information gathering when cooperative behavior is more efficient. An oil company will be concerned about another firm using information to gain an advantage, and hence may overinvest in acquiring still more information. This will give firms less to spend on lease bids, exploratory wells, and reserve exploration, to the detriment of themselves, the government, and ultimately the consumer and taxpayer.

A better system would require greater cooperation in information gathering. Ferejohn, Forsythe, Noll, and Palfrey have recently applied their basic research on auctions for group decisions to the problem of designing a system for oil companies to use to decide collectively the amount and kind of exploratory data that would be most efficient and to allocate shares of the cost of acquiring the information. Since the whole system interacts to determine the motivation for oil exploration, its efficiency is vital to achieving the most efficient rate of discovery of energy resources.

A sticky feature of the problem is to construct a method that takes advantage of the collaboration possibilities without undermining the competitive structure of the industry by fostering collusion in other business activities. The advantage of the group auction approach is that it appears to the participants to operate like a competitive market but leads to a cooperative outcome.

One way the Caltech social scientists are going about designing these new auction methods is with experiments — studying how real people react in choosing among various monetarily motivated alternatives in a controlled situation. Economics and political science have historically not been considered experimental sciences. However, both economics and politics involve the study of choice, and back in the early 1970s it occurred to some faculty members at Caltech, where studies of economics and politics are closely intertwined, that it would be possible to create a situation involving choice behavior, to study it "in small" in the laboratory, and to use the results to test and to refine mathematical models of choice behavior.

Caltech Professor of Economics Charles Plott and alumnus Vernon Smith, BS '49, former Sherman Fairchild Distinguished Scholar at Caltech, and professor of economics at the University of Arizona, were pioneers in developing laboratory experiments in economics. The validity of this research method is now being cautiously accepted elsewhere. Four years ago only Caltech was involved in experimental economics; now a number of other leading research institutions are pursuing it, and Caltech graduate students are widely sought by other universities to intro-

duce experimental methods into their instruction and research programs. Data from experiments are now finding their way into the government and industry policymaking process. And significantly, the National Science Foundation is supporting this kind of experimental research, having financed part of the work of every experimental social scientist on the Caltech faculty.

To be studied in a laboratory setting, a problem must be simple and carefully defined. If a basic theoretical model is expected to apply to complex cases, it must at least work in the simple, special cases set up in the laboratory. And although nothing absolutely conclusive can be learned from these methods about "real-life" situations, experimentation can lead to "very informed guesses."

The social science researchers recruit participants for experiments from all over the Caltech community and beyond — students, staff, JPL, the business community, and others. Those involved find the experiments to be fun, informative, and profitable — sometimes *very* profitable. Since one of the prime tenets of creating a market situation, or adapting market principles to nonmarket situations, is the profit incentive, subjects participate for cash profit, which they keep. Analysis of the experiments is based on the assumption that people will not generally cheat themselves out of the opportunity to earn money in these experimental situations.

Experimental methods have proven very well suited to investigating the properties of auctions. Plott, Gary Miller (a former Caltech faculty member), and undergraduate James Angel used experiments to study the processes used in the auction of Treasury bills, short-term notes sold to banks and other private lenders. Treasury bills are sold to the highest bidders under discriminative pricing; that is, you pay what you bid. Another way of auction pricing when numerous identical goods are offered for sale simultaneously under sealed-bid auction is the competitive or one-price auction, in which all successful bidders pay the price of the lowest accepted bid. Economists have not been able to determine the conditions that would make one type of pricing more advantageous than the other, or which process generates the most revenue to the seller. To find out, Plott, Miller, and Angel auctioned off securities within tightly controlled and monitored economic conditions. Each bidder was given a fixed redemption value schedule for securities that the experimenters would pay if he or she were a successful bidder. These values differed among subjects, and for a given subject the average value fell with volume such that, as the price of the bills fell, the number of bidders willing to buy them would rise. Experimental auction series were run using both types of pricing and different conditions of supply and demand. The experimenters were able to isolate some very distinct properties of the various auction organizations.

Each subject could make a sealed bid for one or more securities in each auction. The limited supply of securities would be awarded to the highest bidders, but the price paid depended on the type of auction. In the discriminative auction, each successful bidder paid the price he bid for the bill, so the individual who made a winning bid below his redemption value earned a profit equal to the difference between the redemption value and the bid. For example, if a security could be obtained by a successful bid of $6.00 by a person who could redeem it for $8.00, the successful bidder would make a profit of $2.00. Individuals submitting unsuccessful bids earned nothing. In such an auction the incentive to bid low to make a higher profit must be balanced against the incentive not to lose out altogether.

After each auction the highest and lowest successful bids were announced. In a series of auctions under stable economic conditions, the high bidders reduce their offers while those bidding too low increase theirs, and over time the bids converge neatly to an equilibrium price — the price that makes supply equal demand (that is, the price at which the number of units for sale equals the number that buyers are willing to purchase at that price).

Similar rules controlled the competitive auction with the exception that all those whose bids were accepted paid the price of the lowest accepted bid. What does that do to the bids? Most people tend to bid higher in such a situation; they want to be included in the accepted bids and assume they will probably not really have to pay as high a price as they bid. And what does it do to the earnings of the hypothetical seller, in this case the Treasury Department? Is the revenue generated higher or lower?

It depends, say Plott, Miller, and Angel. As a result of the very clear data obtained from the experiments, they can estimate almost exactly how much revenue would be generated by each method under different conditions of supply and demand. Which system is better overall depends on how dramatically the quantity demanded responds to a change in price. For example, the discriminative auction makes more money for the seller when the increase in quantity demanded, relative to a given price decrease, is low. When it is high, then the single-price auction becomes more advantageous for the seller.

So what should the Treasury Department do? Since the demand for Treasury bills is not very sensitive to changes in price, the government should probably use a one-price auction, say the Caltech researchers. This has long been suspected and suggested by economists, but before the Cal-

Auctions can get quite heated. This in not a riot but recent gold trading at the International Monetary Market, a division of the Chicago Mercantile Exchange.

Caltech students, also with real profit at stake, submit bids to the "auctioneer" in a pilot Social Science experiment to test theories on a barter economy.

tech experiments, there had been little empirical information to back up the claim. This illustrates an important use of experiments — to explore the performance of new institutional arrangements without risking vast amounts of wealth by immediately implementing them in some real situation.

The ability to generate hard data has led the Caltech economists to try applying auction mechanisms not only to already existing auction situations but to a broad spectrum of other market problems and even to situations involving the allocation of resources that are not ordinarly bought and sold. Auctions have been advanced as a more efficient alternative to government regulation. The use of experiments by Plott, Isaac, and Professor of Economics David Grether to explore new ways to allocate landing rights at high-density airports is one such example.

Eight years ago when the Federal Aviation Authority placed limitations on the number of planes that could land per hour at the country's four busiest airports, a committee of airline representatives was formed to decide among themselves who got to land when. Because the Civil Aeronautics Board decided the airline routes, it effectively controlled the committee.

Since deregulation of the airline industry in 1978, the CAB no longer controls the number of airlines operating at any particular airport. Airports now have more airlines competing for time slots in which to land their planes, and more airlines are represented on the deciding committee. Since Congress or the FAA might end up allocating slots if the airline committee cannot arrive at unanimous agreement, the larger airlines have been effectively forced to give up — grudgingly — some of their landing slots to the new arrivals. Although this process may seem "fair," it is economically inefficient, say Plott, Grether, and Isaac, because the decisions are not based on the underlying economics of the industry. In the long run the committee decision process will hamper the growth of more efficient firms and result in higher fares for passengers.

The Caltech economists ran experiments on the landing rights problem both ways — as a committee process and as an auction, where financially motivated individuals faced problems similar to those that the airlines would face when bidding for the time slots they desired. As a result of these studies, the Caltech team recommended to the CAB that slots be allocated by a sealed-bid, one-price auction with the additional provision of an "aftermarket," where airlines could trade the slots they had won. The economists also suggested that funds generated from the auction of the landing slots be used to expand airport capacity. As might be expected with any recommendation to solve such a complicated problem, aspects of the report are extremely controversial. Airlines, for example, aren't too happy about the prospect of buying landing rights that have historically been provided with only minimal charges. The application of experimental methods, however, demonstrated the plausibility of the technical analysis, and it appears that the recommendations of the Caltech team will become public policy.

One of the especially interesting potential applications of auction mechanisms is to allocate what economists and political scientists call public goods — that is, goods for which the costs and benefits are shared jointly by a group. Allocating shares of the cost is often difficult with public goods, since there is a strong incentive to take a "free ride" — let someone else pay for it but use it anyway. Once the good is produced, any number of people can use it at no extra cost; a case in point is the geological information that is generated about oil lease tracts. Numerous other situations of decision making by large groups involve public goods, for example, condominium residents with different incomes, ages, and tastes seeking to purchase communal playground equipment, or the executive committee of a multi-divisional corporation making decisions about a common R&D program that affects all divisions.

Generally, group decisions such as these are made by majority-rule voting, but for some purposes voting mecha-

nisms are rather clumsy tools. They are not particularly efficient because they cannot readily account for intensities of preference and because they create incentives in some circumstances for participants to misreport true preferences.

Ferejohn, Forsythe, Palfrey, and Noll have been doing extensive experimental work in this area. The first case was the problem of purchasing programs for the public broadcasting network. A television program is a public good in that its production and distribution costs are essentially independent of the number of stations in the network that broadcast it. In the late 1960s, while at the President's Council of Economic Advisers, Noll proposed a market approach to program decisions. In 1974 the Public Broadcasting Service implemented the proposal, adopting an auction mechanism in which stations bid for the programs they want the network to broadcast. Shares of the costs of producing the programs are also assigned on the basis of bids. The system, known as the Station Program Cooperative, is an iterative bidding procedure in which, in each round, PBS sends messages on an interactive computer system to station managers about the programs that remain in the market. Each station is shown a "price" for each program that is calculated by dividing — according to a prearranged formula — the cost of a program among all the stations that voted for it in the previous round of bids. The station responds with an updated list of programs it wishes to purchase at the posted cost shares. A program is dropped when no station desires to purchase it at the last posted price, and is declared purchased when the sum of the accepted cost shares equals or exceeds the cost of the program. The rounds continue until so few changes occur in the station choices that the program prices faced by a station are virtually constant in two consecutive rounds.

The Station Programming Cooperative has been the basis for much of the experimental work on public goods. Refinements of this model and alternatives to it are employed to test new ways of discouraging "free ride" behavior and to perfect the auction's efficiency in different applications.

It was from this model that Nelson adapted his scholarship auction. The scholarships can be considered a public good in that the choice of the best qualified students benefits the entire committee (as well as the entire Institute), and each member of the committee must live with the decision.

Nelson's main problem in conceiving of the committee as a "market" or auction situation was the bidders' lack of any economic incentive. The stake of the committee members in the decision is purely non-economic, consisting of their personal preferences on intellectual grounds for one candidate over another. But Nelson designed a system that established an artificial cost by budgeting votes. What he ended up with was the adaptation of a simplified system "in the spirit of an auction mechanism," which worked well in this case.

First, each committee member listed his top 40 choices out of the total 150 candidates. When these were analyzed, those candidates on everyone's list were considered winners, and those without a single vote were thrown out of consideration. The rest made up the slate for the first round of balloting. The auction system was repeated in rounds, with the choices narrowed down in each round. Each committee member received a "budget" of votes. He could spend his votes on the remaining candidates by casting from zero to five votes for each one. After each ballot, any student receiving 20 or more votes was declared a winner and taken off the slate; since a committee member could cast no more than five votes, no scholarship candidate could be elected by a minority of the eight-person committee. Any candidate receiving less than a required minimum number of votes, which increased with each successive round, was also removed from further consideration.

In between rounds there was time for discussion of the candidates before balloting began again. Voting in rounds gave the faculty members a chance to reconsider candidates on the basis of new information and in relation to others of increasingly similar rank. On each subsequent ballot a voter's budget was reduced by the amount of his votes on winning candidates in the previous round, thus providing a "cost" incentive not to overspend. However, because a candidate could win with 20 votes, any surplus votes were redistributed to the committee members who had cast the greatest number of votes for that student.

It took four rounds and three and a half hours with only minor disagreements to choose 40 students for the scholarships. The faculty committee expressed satisfaction with the selection. Nelson admits that it is probably impossible to design a perfect auction-like mechanism for this case because of the absence of "real" economic incentives. And although the committee members thought the process fair, Nelson observes that the result was not necessarily perfectly "efficient"; that is, it may not have converged on exactly the 40 candidates that were the most qualified according to the combined committee opinions. However, majority-rule voting could not guarantee such an outcome either. For Caltech's financial aid committee the auction at least provided a more efficient means of reaching a complicated decision. □