Procuring Universal Service:
Putting Auction Theory to Work

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I first met William Vickrey in Narita Airport outside Tokyo in 1992. He was on his way back to the United States from China, where, in typical Vickrey fashion, he was using novel theoretical ideas to advise a government about its economic policy, hoping to make life better for large numbers of people. I took the chance to approach him and introduce myself. Soon, we were engaged in a spirited if rather one-sided discussion about the likely effectiveness of some of his proposed policies for China.

Despite Vickrey's intense interest in practical applications, it was his brilliant theoretical work that was emphasized in the prize citation–particularly his path-breaking initiation of the theory of auctions and market design. We can best honor Vickrey's memory today by putting these abstract theoretical ideas to use in real and important applications. My goal in this lecture is to show one way in which that might be done, with an application to the problem of regulating and financing "universal telephone service," which means affordable basic telephone service for nearly everyone.

I have organized this lecture in four parts. The first is a review of some ideas introduced in Vickrey's seminal papers about the theory of auctions. I use the term "auction" broadly to refer to any market process in which the identities of the buyers or sellers and the prices and other terms of trade are determined by an explicit comparison of bids or offers. As used here, the term encompasses both "open auctions" and "sealed tenders." The second part describes the issues involved in implementing universal telephone service in the United States and the kinds of solutions that had been previously proposed. Similar issues arise in every economically developed country, particularly in democracies, as well as in some other industries, such as the electrical power industry. The third part shows how Vickrey's ideas and those of his intellectual descendants can be and are being used to generate new and superior alternatives for dealing with these issues. The final part points out some of the remaining limitations of the analysis.

Vickrey and Auction Theory

Before turning our attention to the details of Vickrey's analyses of auctions, let us pause for a moment to admire the remarkable concept behind them. Before Vickrey's work, economic theorizing about markets abstracted from the detailed rules that determine who trades how much with whom and at what price. In the writings of classical economists like Smith and Marshall and neoclassical Nobel laureates like Samuelson, Arrow, Hicks and Debreu, analysis focused on the conditions of supply and demand. It was these conditions,

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according to neoclassical theory, that determine market outcomes. The theory implicitly assumes that the particular rules governing how bids and offers are combined to determine prices and allocations ultimately has no effect on market outcomes..

Vickrey's analysis rejected this tenet of the neoclassical approach. It paid detailed attention to the rules of the market and found that, sometimes, the level of prices, the quantities traded and the identities of the traders could depend in important ways on these rules. Vickrey's papers included the first formal analysis using theory to devise new auction rules to make efficient outcomes more likely. Using what has since been learned from theoretical analyses and laboratory experiments that test alternative rules, we have become increasingly adept at designing the rules of markets to accomplish various ends, improving dramatically on older auction designs. In the past two and a half years in the United States, for example, commercial licenses to use portions of the radio spectrum for new services have been sold using novel auction designs suggested by theory and tested in economics laboratories. These auctions have been used on a large scale–over $20 billion has been raised–and led to apparently efficient license assignments and prices that appear to fairly reflect values. The outcomes of these auctions contrast sharply with the relatively inefficient and low revenue outcomes obtained in spectrum auctions in New Zealand and Australia in 1990 and 1993.

This lecture presents another new market design, taking another step along the path that Vickrey blazed in 1961 and upon which many have since traveled.

The appropriate framework for a formal analysis of alternative auction mechanisms was hardly obvious in 1961. Even to begin the analysis, one needed a new model in which the relevant questions could be posed. Vickrey solved that problem by introducing a tractable class of game theoretical models that are now known as *independent private values models*; these are the ones most often used to study questions in auction theory. In his analysis, Vickrey represented the bidders' uncertainty about one another's likely bids by supposing that bidders draw random "values" for the items being sold according to some probability distribution. They make their bids dependent on their values, with economic forces determining the levels of their bids. He studied several different formal bidding games sharing the elements just described. The games differed in the number of goods offered for sale, the distribution of bidder values, the symmetry or asymmetry of the players' value distributions, and the rules of the auction. All these variations were studied using what we would now call *Bayesian Nash equilibria*, a concept that was first introduced and formalized more than half a decade later in the work of Nobel laureate John Harsanyi, and it was a full decade before others would begin to see how to apply these ideas to economic analyses.

The main technical elements of Vickrey's analysis, including especially the independent private values model and Bayesian Nash equilibrium, are incorporated into the analysis of the universal service problem given below.

Vickrey's 1961 paper reported a number of results that would ultimately prove to be very significant. One – now known as the *revenue equivalence theorem* – holds that in certain environments, several popular auction mechanisms including the ascending bid auction commonly used in English auction houses, the descending bid Dutch auction, and the ordinary sealed tender implement an efficient outcome and generate the same average receipts for the seller. At the time, this result might have seemed to suggest it really is the conditions of supply and demand, rather than the details of the auction process, that determine market outcomes. On closer examination, however, it also contains the seeds of another insight, namely, that certain objectives, including efficiency of the allocation and seller revenue, can be maximized by more than one auction design, leaving freedom for the auction designer to accomplish secondary objectives at the same time as maximizing revenue or efficiency.

Vickrey himself recognized the importance of that insight. He showed that a new auction design first proposed in that paper – a sealed tender in which the highest bidder receives the item but pays a price equal to the second highest bid – achieves the same efficiency as the other mechanisms but, unlike other kinds of auctions, also gives each bidder a *dominant strategy*, namely, to bid its own value. (A dominant strategy is a strategy that is best for the bidder regardless of the strategies of the other bidders.)

Vickrey had argued that dominant strategies are desirable because they eliminate bidders' incentives to waste resources trying to learn about their competitors in efforts to infer what they might bid. One could add that by eliminating such guesswork, they make it more likely that the efficient outcome will result than do alternative auction mechanisms. Indeed, for auction mechanisms like the standard sealed tender to result in efficient allocations, each bidder needs to guess correctly about the distribution of competing bids made by other bidders. And, even when the bidders do guess correctly, the alternative designs yield efficient outcomes only in a very limited class of environments, primarily those in which the bidder's types are identically distributed. Vickrey's proposed new design does not require either correct expectations or symmetric environments; it is a much more reliable way to achieve efficient outcomes.

Universal Telephone Service

The problem we will discuss today is how to make affordable basic telephone service available to everyone (in the United States). Achieving this goal is expensive, for two reasons. First, some customers have such low incomes that even modest telephone charges are unaffordable. In the United States, programs designed to subsidize telephone service to low income customers are called "lifeline service" programs. Second, it is quite expensive to provide telephone service to residents of some geographic areas. Establishing service to remote customers, such as those living on farms and ranches in rural areas, may require running long wires through difficult terrain to serve a small group of telephone subscribers. Even within urban areas, the costs of connecting different customers to the telephone network can vary among customers by a factor of ten. Programs designed to pay part of the cost of providing service to high cost areas are called "universal service" programs.

There are many reasons commonly cited for making affordable telephone service available to everyone. In purely economic terms, one may argue that a customer who hooks up to a telephone network provides a service not only for his household but also for everyone else on the telephone network who may ever want to contact him. This "network externality" justifies some public subsidy to promote more extensive use of telephone service. In addition, hooking people to the telephone network may be the cheapest way for the public sector to fulfill obligations such as providing public health, safety and emergency services. Without telephones to allow residents to call for help, public safety agencies might need to rely on more expensive spotters and patrols. Avoiding those costs provides the public with a direct financial interest in promoting widespread use of telephones.

There can also be important political and social reasons to promote widespread telephone and other communications services. A democratic society has an interest in keeping its citizens informed about developments throughout the country and perhaps the world and in providing a means for them to communicate effectively with their representatives and among themselves. It also has an interest in preventing social fragmentation in which households or whole communities live with few connections to the rest of the polity. Universal telephone service advances these interests.

In practice, implementing a program of universal service involves first defining "basic telephone service." What services should be included? What additional options should be available? What level of quality should be maintained? Second, an affordable price must be established. Third, a service provider or providers must be identified, and a means must be found of footing the bill.

In the United States, basic local telephone service has been implicitly subsidized both through reduced prices for basic telephone service supported by higher prices charged for other telecommunications services, such as long distance calling, and through the use of uniform telephone rates over wide areas. In California, for example, even today, anyone in the area serviced by the largest telephone company, Pacific Bell, can purchase basic telephone service for $11.25 per month. This price is the same for hillside dwellers in remote mountain communities as for residents of large apartment buildings in downtown Los Angeles, even for apartments that are just a block away from the main telephone switch. The phone company's cost per phone line of hooking the apartment and its residents into the system, though, is much lower than for the mountain dwellers, because a single short high capacity wire can be used to provide service to all of the large building's residents. The implicit subsidies in the system are enormous: one estimate for the subsidy to rural service alone is about $5 billion per year[2] and the estimated size of all rural and urban subsidies is higher still.

So long as local telephone service was provided by monopolies that were free from competitive market constraints, this system was sustainable. In recent years, however, this pattern has been breaking down. New phone companies have sprung up to offer services in places like Manhattan (mostly for business customers so far), where the high density of telephone lines makes the average cost of service quite low. With the passage of the Telecommunications Act of 1996, which deregulates much of local telephone service and seeks to promote increased competition in all parts of telecommunications, a system of uniform local service prices for all customers is rapidly becoming untenable. The Act provides for the establishment of a fund to subsidize service to customers in high-cost-of-service areas. The Act also requires that the subsidy levels in each area be adequate to cover the universal service provider's costs.

It is now the task of regulators to decide how to implement the Act's provisions, keeping in mind the two main goals of encouraging competition in the provision of telecommunications

[2] *What Price Universal Service?: Impact of Deleveraging Nationwide Urban/Rural Rates*, Telecommunications Industries Analysis Project, Cambridge, MA., 1993.

services and keeping down the cost of subsidies (and the taxes needed to support them), as well as subsidiary goals like reducing the need for ongoing regulation.

With these goals in mind, two main kinds of policy options have been discussed. The first calls for the use of an auction in which bidders name the price they require to accept a universal service obligation in a service area. This means that the selected suppliers stand ready to offer a prescribed basic service package at a prescribed "affordable price." The advantage of this option is that competition among would-be universal service providers could drive down the necessary level of subsidies. Also, once auctions are conducted, there would be no further need for cost studies to determine appropriate levels of subsidy to a monopoly telephone supplier. Nevertheless, this option is often regarded as unsatisfactory because it results in a single provider in each service area. With neither competition nor regulation to discipline the single provider, there would be little pressure on it to introduce new services and maintain high standards of quality. Also, new telephone providers may be able to bring valuable new services, like cheaper long-distance calling, or packages including telephone service with wireless or cable television services. Having a single provider denies these potential new services to customers.

The second option calls for estimating the costs of providing basic service in each area and then making that level of subsidy available to any company that is willing to accept a universal service obligation for the area. This makes competitive entry relatively easy, with all the advantages that competition entails. However, it has two big disadvantages. First, because it bases subsidies on the existing wireline technology and ignores and revenues from new services that might be delivered over the telephone network, it locks in the subsidies at an unnecessarily high level. In addition, it requires ongoing regulatory intervention in the form of both cost studies (to meet the legal and practical requirement that subsidy levels are adequate) and coercive service requirements on the incumbent telephone company at the established subsidy levels.

Each of these options has advantages and disadvantages and one might expect that the optimal system could vary for different service areas around the country. Is it possible to implement different systems in different areas? Is there some system that is better than either of these in every case?

An Optimal Auction Mechanism for Universal Telephone Service

Using the theory of market design that Vickrey initiated, we can ask questions about what organization of the universal service market is best taking into account both the desire to promote competition and the desire to keep the total subsidy cost low. In the process of answering these questions, the analysis generates an important new alternative in which the number and identities of the competitors is determined by the market process itself, rather than being set by fiat as in traditional auction proposals. In particular, the new approach allows different market structures in different geographic regions, as is certain to be appropriate given the very different cost conditions that prevail in different areas. The new auction mechanism does a much better job than either of the other proposals of balancing the two objectives of promoting competition "in the market" after the auction, to promote better service and more variety, and competition "for the market" in the auction, to reduce the level of subsidies that need to be paid.[3]

Because the actual situation in supplying universal telephone is so complex, the theoretical analysis advanced here aims only to capture a few of the most important features of the real situation. We begin by specifying the objective of the whole exercise, which is to maximize a "total welfare" criterion or objective consisting of three terms:

Expected Benefits to Consumers
+ Expected Profits Enjoyed by Service Providers
– a Expected Subsidies Paid to Providers

The first term is the benefits enjoyed by the consumers in an area, which depends on the level of competition in the local telephone market. More competitors vying for customers can lead to various benefits for consumers, including more variety, better service offerings, and more responsive service. More competitors may lead to lower prices, too, if splitting the market does not increase costs too much. To account for the interests of telephone company shareholders, we add the firm's profits to the social objective.

These two initial terms, however, do not include all the economic benefits and costs. The taxes or surcharges used to pay universal service subsidies distort choices made in the economy and result in a loss of welfare. For example, if universal service were funded by a tax on long-distance calls, that could result in fewer such calls being made–calls that would be made if the price of long-distance calling were not made artificially high by the additional tax. The welfare loss from such distortions is approximately proportional to the total subsidies paid; it is captured by the third term in the formal objective.

To simplify the problem for this presentation, we make a number of assumptions whose significance we discuss briefly at the end of this lecture. We focus on the case where there is a single region in which universal service is to be provided and where all subsidies are paid in the form of a lump sum. There are assumed to be N bidders indexed as i=1,...,N.

Each of the bidders has a cost "type" q_i that determines its cost of providing service to some or all of the customers in the service area. We may think of lower values of q_i as corresponding to lower total and marginal costs for firm i in a way that allows it to earn greater profits in any particular competitive situation. Let q denote the N-tuple $(q_1,...,q_N)$. Let $p^i(q,S)$ denote the profit earned by firm i when the set of firms receiving subsidies to accept the universal service obligation is S and let $B(q,S)$ denote the benefits enjoyed by consumers. We assume that (1) profits and consumer benefits depend only on the types (q_i,i Î S) of the firms in S, that is, the firms actually providing telephone service, (2) a firm can earn profits only if it is authorized to supply subsidized service, that is, $p^i(q,S)$=0 if i Ï S, (3) $p^i(q,S)$ is continuously differentiable in q_i, and (4) for all q and all $i \in S$, profits are decreasing in q_i: $p_i^i(q,S) \equiv {}^{\P p}/_{\P q_i} < 0$.

The auction that is implemented, including the rules for the kinds of bids that can be made and the way firms behave in the auction game, determines which firms will receive subsidies in

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[3] A 1994 paper by James Dana and Kathryn Spier (which I unfortunately discovered only after delivering this lecture) provides a nearly identical analysis of virtually the same mathematical problem that is treated here, but with other applications than universal telephone service in mind.

exchange for bearing the universal service obligation and what subsidy payments they will receive. The actual outcome of the auction cannot be predicted in advance because it depends, of course, on the cost types q. One can describe the likely outcomes by a set of functions which express the probabilities $p_S(q)$ that S will be the set of firms selected to be suppliers when the cost types are given by q and the corresponding expected levels of subsidy payments $x_i(q)$ to each firm i. With the outcomes described in this way, the corresponding expected level of welfare, given q, is:

$$\sum_S p_S(q)\left(B(q,S) + \sum_{i \in S} p^i(q,S) \right) - a \sum_{i=1}^N x_i(q) \; .$$

The expected value of this welfare measure is to be maximized by choosing functions $p_S(q)$ and $x_i(q)$ (i=1,...,N) corresponding to a feasible auction and associated bidding behavior. For the expected value calculation, we assume that the q_is are independent and distributed according to distribution functions F_i with corresponding densities f_i, i=1,...,N. Thus, expected welfare is:

$$\int \left[\sum_S p_S(q)\left(B(q,S) + \sum_{i \in S} p^i(q,S) \right) - a \sum_{i=1}^N x_i(q) \right] f(q)dq$$

The trick to analyzing this problem is to characterize the constraints on the p_S and x_i functions that are implied by our postulates concerning how the bidders will behave. Following Vickrey, we assume that the bidders act to maximize their own profits, given correct expectations about how others will bid. That is, we assume that the bidders will play a Nash equilibrium of whatever auction game we may design. To solve the maximization problem, we utilize techniques developed in the Roger Myerson's 1981 analysis of auctions that maximize the seller's expected revenues.[4]

The full details of the mathematical analysis will not be reported here. What Myerson's analysis demonstrates is that the p_S combined with the avoidance of unnecessary subsidies to losing bidders together determine the necessary expected subsidy levels $E[x_i(q)|q_i]$. This allows one to substitute for x_i in the objective function, rewriting it as the expectation of the following alternative objective function:

$$\sum_S p_S(q)V(S,q)$$

where

$$V(S,q) = B(q,S) + \sum_{i \in S}\left((1+a)p^i(q,S) + a p_i^i(q,S)\frac{F_i(q_i)}{f_i(q_i)} \right).$$

The function $V(S,q)$ is called the "*virtual welfare*" function. We limit attention today to what is sometimes called the "regular case," in which for each S, the virtual welfare function is decreasing in q. The upshot of the analysis is the following:

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[4] Myerson's techniques themselves build on the methods introduced by Vickrey's co-laureate, James Mirrlees, in his 1971 paper about taxation.

Proposition. *In the regular case, an auction design is optimal if and only if it results in outcomes in which (1) for almost every* q*,* $p_S(q)=1$ *for the S maximizes V(S,q) and (2) the expected net profits (gross profit plus subsidy) of the highest cost types are zero.*

The most striking aspect of an optimal auction is that it necessarily entails *endogenous market structure*. This means that the set of firms participating in the market depends on the firm's cost characteristics, which is the private information of the firms. If there are several independent regions in which universal service is to be supplied, the result is that different numbers of competitors may be present in each, according to the privately known cost information of the firms.

In determining the optimal set of firms to include in the market, the profits of the firms are given extra weight in the virtual welfare function compared to the original social objective: it is multiplied by $1+a$. In addition, $V(S,q)$ includes terms (F_j/f_j) to account for the bidding incentives of the firms. Awarding universal service subsidies to many firms tends to reduce the incentive of each firm to bid aggressively, since even a less aggressive bid is more likely to result in a reward. Therefore, unless there are diseconomies of scale (which is unlikely in practice), one consequence of designing an auction to allow multiple universal service providers is higher average subsidies. An optimal auction design takes that effect into account, typically reducing the number of firms both to increase pre-subsidy industry profits and to increase the intensity of competition "for the market."

Although the optimal auction analysis generates quite specific statements about which firms should be in the market in each specific circumstance (identified by q), it does not specify a unique rule for how payments should be made. This conclusion was foreshadowed in Vickrey's 1961 paper, in which he found several auctions with different payment rules that all led to efficient allocations in certain simple contexts, and that also all led to the same expected payments by bidders. In the present more complicated context, Vickrey's insight still applies: there are many different optimal auctions, that is, many payment rules that can implement the allocation rule identified in the Proposition.

The multiplicity of optimal payment rules means that there is scope for using the payment rule to pursue secondary objectives. One such objective is to arrange that each bidder has a *dominant strategy*. The advantages of dominant strategies, as identified by Vickrey, have already been explained. The basic rule for making truthful reporting of cost data a dominant strategy is also one that Vickrey (1961) had identified. One does that by "paying each seller for his supply an amount equal to what he could extract as a perfectly price discriminating monopolist [against the residual demand curve]." In this case, the analogous rule is as follows: For each q, pay firm j a subsidy that makes its post-subsidy profit equal to the increase in the maximal value of the virtual welfare function, $V(S,q)$, that results from expanding the set of available firms $N\backslash\{j\}$ to N. This rule implements the allocation identified in the Proposition, and makes truthful reporting a dominant strategy.

Another possible secondary objective is to pay uniform subsidies to all subsidized universal service suppliers. There may be legal reasons to prefer uniform subsidies. Uniform per subscriber subsidies may also be desired because they avoid advantaging any particular competitor when the competition for customers begins. Although uniform subsidies are possible, it is not possible to achieve both uniform subsidies and dominant strategy implementation of the optimal auction.

Limitations and Possible Extensions

The foregoing analysis is a preliminary one that is valuable partly because it introduces a new approach to regulating and financing the provision of universal telephone service. However, the recommended approach is only as good as the underlying model. The model itself omits several possibly important factors.

One of the most important assumptions of the model is that subsidies are paid in the form of a lump sum, regardless of the number of subscribers served. In reality, lump sum subsidies are highly undesirable, and the political discussions have focused primarily on per subscriber subsidies. Because subsidies are needed only for high-cost customers for whom service is unremunerative, it is necessarily wrong to suppose that service would be voluntarily provided at all, let alone at the same level, if subsidy levels were low. To put the point more generally, the level of subsidies is likely to affect the intensity of competition among suppliers, and the existing model fails to account for that.

A second potentially important omission concerns variations in costs among customers in the area of universal service. If the cost variations are large across the service area, firms may be tempted to offer service only to the customers in the lowest cost segments of the service area. That problem could be resolved by running auctions for smaller, more homogenous areas, and indeed such a proposal has been made in the United States. However, if small service areas are specified for the auction, it may be inappropriate to consider the costs of service separately for each area, because there could be important shared costs among them. As of the date of this lecture, the importance of such shared costs for universal service remains an open question.

Finally, during the transition to competitive provision of local telephone service in the United States, the incumbent local exchange carriers continue to have a special obligation to offer service. The analysis suggested here has been vague about the details of how the transition will be made. The timing of auctions in different service areas could be important, as could issues about the relation of the auction rules to other local competition rules. All of these details need to be worked out carefully if universal service auctions are to be successfully implemented.

Conclusion

Throughout most of his career, Vickrey was interested in ideas that were immediately applicable to problems that concerned him. He was particularly proud of his work on the New York subway system, on which he had expended enormous effort. Given that perspective, Vickrey would probably have been surprised to learn that his 1961 paper, which he thought of as abstract theory, could be the basis of something so useful as practical market design.

The fact is, however, that it has been just in the past fifteen years that new contributions building on Vickrey's pioneering work have advanced the theory of auction design sufficiently to make it widely useful for applications. Despite its theoretical depth, or more likely because of it, Vickrey's contributions to auction theory may have been his most practical work of all.

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