Incentive Compatible Space Station Pricing

By JOHN O. LEDYARD*

Space Station, planned to be operational in the mid-1990's, provides an example of the opportunities and difficulties associated with the development of space. This project, currently projected to cost some $8 billion just to reach operational capability, is being designed to achieve several goals, among which are the encouragement of the commercialization of space, the promotion of international relations through the inclusion of international partners, and the continued promotion of space science and technology. Space Station is to be a continuously manned platform in low earth orbit, providing a variety of resources (for example, power, a low gravity environment, manpower, and laboratory space) that can be used by NASA and others in conjunction with their payloads to further these goals. The station is a highly complex, multidimensional *R&D* project for which good management will be necessary if it is to be successful.

In this paper I discuss several possible contracts between NASA and others and their implications for the operation, pricing, and evolution of Space Station as a major space project. Unalterably interconnected with these pricing policies are the allocation of resources produced on Space Station and the extent of the benefits to be received by the users. Although it is sometimes difficult for an engineer to accept, prices will affect behavior and use patterns, which in turn will affect the ultimate gains from any project designed to operate over a long period of time. Modern economic analysis provides us with a way to analyze these implications and evaluate their impact on the desired goals.

The economic theory that provides the most insights is called mechanism theory or the theory of implementation. A brief survey on topics relevant for this paper can be found in Roy Radner (1986). For now, it is important only to understand the general framework of this theory of organizational design. There are two key hypotheses: 1) the information needed to achieve organizational goals is initially dispersed and difficult to uncover through direct monitoring; and 2) individuals will reveal that information and respond to instructions and requests only if it is in their interest to do so. The designer of the institutional rules, that specify who tells what to whom and who carries out what actions, can do nothing about the initial distribution of information or the motives of the various actors in the organization. The designer can only optimize the organizational goals subject to the informational and incentive constraints. But, within these constraints, there may be a wide range of options, some of which are more desirable than others.

To apply the insights of this theory I first describe the Space Station environment (those features of the project which are not really under the control of the designer), then briefly discuss some of the goals which have been proposed, and finally discuss several options for pricing. I conclude with an open question for research.

I. The Space Station Environment

In this section I briefly describe some of the aspects of Space Station that are important from the point of view of the economist as a designer of organizations and which effectively lie outside our control. (Those interested in a more detailed formal analysis should consult my 1984 paper, or Jeffrey Banks et al., 1985.) The key observation is that Space Station is a multiple-product, highly uncertain, public enterprise, among whose clientele are a wide spectrum of users from the public and private sectors.

*California Institute of Technology, Pasadena, CA 91125. Some support from NASA was provided for this research. They bear no responsibility for this paper.

A. *Technology and Costs*

In simple terms, Space Station is a multi-product public utility. A major initial capital-intensive investment produces an entity which provides a stream of resources over time, requiring relatively low and, probably, reasonably constant per unit operating costs. However, the differences between Space Station and a standard utility are important. On Space Station the technology is not well understood. Uncertainties exist because these technologies have never before been operated in space at this scale. Secondly, the resources that will be produced are also required as inputs: power is not only to be supplied to users of Space Station, it is also a required input to the life-support and command systems. Since there are significant uncertainties about how many of these resources will be needed for internal use, there are derived, magnified uncertainties about the net amounts available to users. These housekeeping needs should be known once Space Station is fully operational but, for all contractual agreements made prior to the mid-1990's, this is a major uncertainty. Similarly, because this technology is new, there is a lot of uncertainty about the costs of construction and operation. This is, therefore, a large complex project for which comparable endeavors are difficult to find. Standard public enterprise or regulated utility models in which there is a fair degree of certainty about the technologies, costs, and demands are simply inappropriate as models of Space Station.

B. *Demand and Benefits*

There will be an incredible variety of users of Space Station, but for the purposes of this paper one can think of five main categories: commercial users, NASA science and technology missions, other U.S. government users (mostly Department of Defense), international partners (Canada, European Space Agency, and Japan), and all others. Although each of these user classes presents different problems and constraints with respect to pricing policies, they have one thing in common. Benefits and demand are highly uncertain to them and to the designers and operators of Space Station. As economists, we have absolutely no way to use modern econometric analysis to estimate demands (and therefore, perhaps, to estimate consumers' surplus) as might be done in the design of pricing policies for public electric utilities. We also cannot simply ask potential users of Space Station how much of each resource they wish to consume and then plan around the aggregate response. Even if they were certain of their benefits, they have little incentive to reveal all their information. If charges do not depend on their responses, then they have an incentive to overstate their needs; if charges depend on their responses, then they have an incentive to claim only marginal benefits from use. There are no independent market data that NASA can use to check the validity of the data. (Some data are available from STS, the shuttle missions, which with the exception of satellite launches have tended to be short-term research projects flown for virtually no charge. There appears to be very little relationship between these and the long-term projects envisioned for Space Station.) Any pricing rule or other organizational choice must, therefore, not assume that accurate demand or benefit information is available. This immediately rules out a number of policies normally touted in the literature and in the halls of Congress.

II. Pricing Goals

In order to provide a reasonable analysis of alternative pricing policies for Space Station, we need to first consider the goals. What is one trying to accomplish with the pricing policy? As any economist should expect, two desired outcomes are 1) the recovery of some or all of the costs of design, development, and operation, and 2) the Pareto-efficient utilization of Space Station once it is operational. Pareto efficiency implies, for example, that given any particular vector of desired outcomes, the aggregate lifecycle costs of the station and all of its payloads should be minimized subject to achieving those outcomes. This is broader than the goal of minimizing only station costs, but is appropriate from an economywide perspective. Minimization of station costs in a way that imposed significant burdens on the users' costs of building and operating their own payloads would not only be Pareto inefficient, but also may be politically risky for NASA.

Three other goals that may be at least as important as the first two are the promotion of 3) the commercialization of space, 4) science and technology, and 5) international relations. These are important since they relate to the three major user groups: private industry, NASA science and technology missions, and the potential international partners. It is well known that for projects with large set-up and common costs and small operating costs, it is generally not possible to satisfy all five goals simultaneously. For example, a naive approach to achieve goals 3–5 would be to provide station resources free to those users. This obviously conflicts directly with the goal of cost recovery. Less obviously, there is also a conflict with the goal of efficient utilization; too few users will use too many resources. Thus, although a small number of potential users would benefit from a "free access" policy, a larger benefit can be obtained from a more efficient pricing policy. I am prepared to argue that the latter three goals are all advanced if Space Station is utilized and operated in as efficient a manner as possible, and that they are hindered if the pricing policy is inefficient; there is no conflict with the second goal. Efficiency means "more bang for the buck," more resources per dollar input, which means more payloads of all types are able to be accommodated.

The real question, then, is the common one: can the conflicting goals of cost recovery and efficiency be dealt with in a sensible way? For traditional projects with large set-up costs, low marginal costs, and a fair degree of certainty, economists have suggested Ramsey pricing to maximize benefits subject to covering costs. This policy requires either direct knowledge of the demand functions (to estimate consumers' surplus directly), or a tatonnement process with little misrepresentation. Neither option is available for Space Station: demand and benefit uncertainties rule out the former, while cost uncertainties (combined with an application of the Revelation Principle) seem to rule out the latter.

III. Cost Recovery through Posted "Average Cost" Pricing

One simple proposal, intended to accomplish the goal of cost recovery with little damage to efficiency, would be to charge a price for each payload equal to the cost of its STS (shuttle) flight plus a percent to cover the rest of the costs of accommodating it on Space Station. (For now I put aside the problems involved in determining which costs are to be recovered: design and development, construction, launch, and/or operating costs.) This is a reasonable policy only under two assumptions: 1) the designers, builders, operators, and users of Space Station are a team (in the sense of Jacob Marshak and Radner, 1972); they are in agreement about the goals for Space Station and, although perhaps asymmetrically informed, are willing to provide any information they have when requested; and 2) no user will alter his decisions as a result of the prices he is charged (prices only allocate costs, not resources). Both assumptions are false. One need only consider the current pancake-shaped engine for satellites developed by Hughes Aircraft in response to the pricing policy for the STS shuttle to realize that even engineers respond to price incentives. This is especially important for Space Station since that project truly broadens the user classes to include other than U.S. government funded missions.

It is easy to predict what would happen if "shuttle plus a percent" were instituted. Payloads would be designed to conserve on weight and length, but not on either power or manpower, two of the station resources which are projected to be in a constant state of excess demand. Since time on station is not included in the billing calculation, long-term missions requiring a lot of tending by mission specialists will be preferred by the users to brief missions even if the latter use few station resources. Designers are trying to build the best station possible at the lowest possible initial cost. Although they recognize the need to minimize the present discounted costs of construction and operation, the congressional budget constraints they have been given do not encourage intertemporal tradeoffs. The designers have incentives to minimize construction costs and to hope that operating costs will not be too bad. Robotics are ignored; manpower will do. Methods to conserve consumables will be downplayed; shuttle trips can be expanded. This will not be intentional, simply the rational response to the constraints and pressures placed on the builders. High operating costs mean more expensive, or perhaps fewer, resources once the station is operable. This form of pricing policy leads inevitably to inefficiency, and does not implement most of the goals of Space Station.

IV. Efficiency through Posted "Marginal Cost" Pricing

A natural way to rescue some efficiency is to price each critical resource. This can be done by posting long-run marginal costs, two-part prices, short-run marginal costs, or Ramsey prices, and agreeing to supply demand up to the amount available. Each specific policy yields different implications for the level of benefits obtained and the revenue received, but the posting of prices that approximate expected marginal costs will definitely lead cost-conscious users to design payloads to conserve on those resources whose supply is relatively difficult or costly to expand. But some difficulties exist. The extreme uncertainty concerning costs means that either users will find it difficult to impossible to predict what the marginal cost prices will be, or NASA will have to post an expected value and absorb all the risk themselves. The latter seems to be a no-win situation for NASA. If the posted prices are lower than marginal costs, then Congress or NASA must absorb the loss (causing potential difficulties for future NASA funding), and if the posted prices are higher than marginal costs, then users will be outraged (also causing potential political difficulties). The former is also bad. Uncertainty over prices will cause risk-averse users to postpone development of payloads that should go now. Also, with sufficiently variable supply, even if payload builders feel they can correctly anticipate prices and proceed with their own expensive *R&D* programs, the possibility exists that they may be rationed out in the early years (until appropriate expansion can occur). For small, short-duration payloads this may not be much of a problem; for large, long-duration payloads they should be intolerable and should lead to fewer of this type of mission than is efficient. The standard solution for this problem is some type of insurance arrangement, provided either by NASA or private markets, like that initially available for shuttle launches of satellites.

V. Efficiency through Contingent Contracts

Posted prices, even if they equal long-run marginal cost, may lead to inefficient utilization of the Space Station because of the large uncertainties involved in the new technology and because of the risk attitudes both of potential users, and of Congress and its electorate. When there are large uncertainties about costs or supplies (large as a percentage of the project), not controlled by either supplier or user, and both parties are risk averse, then contingent contracts can make both better off and improve efficiency. In the move which usually works, it is agreed to deliver more of the uncertain output (for less per unit) if supply is large and costs are low, and to deliver less output (for more per unit) if supply is scarce and costs are high. Agreements to supply an amount conditional on total resource availability at the realized long-run marginal cost per unit would be one type of contract like this. There are obviously many others.

The difficulties in writing such contracts arise in identifying appropriate "mutually verifiable (without costly monitoring) and exogenous (independent of each others actions) events" on which to make the contracts contingent. On Space Station the true realizations of both supply and costs are partially under the control of NASA, its engineers, and the builders of the station. For example, if NASA controls all the nonlaboratory aspects of the Station, it has an incentive to include as much of its own power consumption under the housekeeping rubric as it can.

(Power used to support manpower in medical experiments may be accounted as used for life-support systems for the crew.) Cost manipulation like this would be even harder to detect directly. International partners and major commercial users, among others, are suitably skeptical about NASA's ability to keep operating costs (much less construction costs) under control. They need only look at the early predictions of shuttle operating costs and compare them to the actual realizations to support their suspicions.

On the station, almost all easily observable events one could possibly use for contingent contracts are the compound result of the actions of one actor and some exogenous event. These are difficult to separate to the satisfaction of all parties without extensive monitoring and auditing. It is therefore unlikely that these types of contingent contracts will lead to the efficient operation of the Space Station. The standard solution to this moral hazard problem is the use of principal-agent contracts.

VI. Principal-Agent Contracts

If moral hazards exist, but it is possible to organize the project so that the uncertainty is either exogenous or under the control of a single party (the agent), and if that agent is less risk averse than the others (the principal(s)), then the efficient contract consists of giving the agent full control of the project, giving that agent rights to all the uncertain benefits and responsibility for the uncertain costs, and paying the other(s) a fixed fee (possibly negative, possibly in kind) which is not contingent on any of this. As an example, NASA could agree to deliver a fixed vector of resources to each user in return for a fixed payment (to be negotiated). If NASA is risk neutral, this is the most efficient contract; given any other contract, there are terms of exchange for this one such that both NASA and the user are better off.

For large contracts (that involve, say, one-third of the projected power to be supplied), NASA does not appear to be risk neutral. Then the efficient contract involves the agent laying off some of the risk on the principal in return for better terms of trade or a reduced fixed fee. In profit-making operations this can be done through a profit-sharing arrangement (for example, the principal gets 20 percent of the net profits in return for an investment of $1,000), but on Space Station there is no market for much of the output, and therefore any such arrangement must be in terms of the resources to be supplied. A user who projects a large resource demand for a long duration might be willing to take 20 percent of the realized net resources of the station in return for a payment of some fixed amount initially. This type of user would probably be either a private venture capitalist, buying for resale, or a large, non-U.S. government user, such as one of the international partners. Of course, resale would be allowed to improve efficiency. This type of contract readmits the moral hazard problem, but the user accepts this in return for some concessions on price.

There are three other difficulties with principal-agent contracts. NASA cannot keep its savings because of the form of congressional budgeting; this blunts its incentives as agent. Over time, evolution of the station must be managed to contend with new users and new information; an agency contract does not necessarily provide the correct incentives for situations with extensive learning-by-doing. Finally, many aspects of Space Station use rely on inputs from both the user and the Space Station managers. If it is not possible to organize in a way that isolates the effects of each parties' actions from the other, then some form of partnership arrangement is needed.

VII. Partnerships

When the inputs of both parties are needed to obtain an output, and when the inputs cannot be easily monitored or separated from external exogenous events, then principal-agent contracts are inappropriate. In the operation of a lab module it may be impossible to identify the separate contribution of either party to the success or failure of an experiment. Was it the failure of the command crew, under the control of NASA, to maintain "zero g" or did the payload specialist, under the control of the user, unintentionally "bump" the payload too hard? If one cannot separate these effects, then it is possible that some agreement in which all costs and benefits (resources) are shared (a closely held partnership) may leave both parties better off than under an agency contract.

The major difficulty with partnerships is the "free-rider problem." When separate effects cannot be identified easily, both parties have an incentive to shirk. This is especially true in *R&D* projects like the Space Station where benefits are not marketable. Only if this is a very long-term, repeated relationship so that tit-for-tat arrangements can be implemented do partnerships of this form appear to be viable. It is also helpful if there are some (possibly imperfect) publicly available measures of individual performance. I have come full circle to the team problem of Section I with the added twist of shares in the resources and costs. Little is known about efficient contracts and incentive compatible pricing in this situation. More research is needed.

VIII. Conclusions

Space Station is a complex, multiproduct public enterprise with large uncertainties about the implications of its technology. It is also the potential prototype of many more. Pricing policy will affect the efficiency of use of Space Station and its evolution. But pricing policy is constrained by the location of information and by the incentives of all participants. For small users, such as non-NASA U.S. users and nonpartner foreign governments, efficiency seems best served by either a contract contingent on the realization of long-run marginal cost and net supply, or, if moral hazard is a fear, a fixed-fee contract for the delivery of a fixed amount of resources. For large users, such as the potential international partners, this arrangement would not be appropriate for NASA. In that case it is best to organize so that each individual is responsible for their own actions through a principal-agent contract. (Each user and NASA could be both an agent on one contract and principal on another.) If that organization is not possible, then some form of partnership is probably efficient, the precise nature of which is not yet known. There are organizational solutions to the management problems that have tended to trouble large uncertain *R&D* projects in the past. It is time to be as imaginative and daring with these management solutions as NASA has been with its engineering solutions.

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