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PRIVATE R&D AND SECOND SOURCING IN PROCUREMENT: AN EXPERIMENTAL STUDY

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ABSTRACT

This study focuses on two topics in government procurement problems: second sourcing, and private research and development investment in procurement. A simple theoretical framework is developed to analyze the likely effects on private R&D and procurement prices of recent proposals regarding competition in procurement and the associated data-rights policy. The framework is also used to demonstrate a major flaw in the current methodology used in the evaluation of the benefits of second sourcing. The framework can be used to identify a competition-reduction effect of second sourcing. In procurement environments where private R&D is an important factor and potential sellers have commercial markets which may be adversely affected, second sourcing may reduce competition in the initial procurement stage. Experimental methods are used to test for the existence of the effect.

PRIVATE R&D AND SECOND SOURCING IN PROCUREMENT: AN EXPERIMENTAL STUDY*

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A presumption exists that greater reliance on competition in procurement policies will result in substantial cost savings to the U.S. Many policies have been changed and many are in the process of being changed as the Department of Defense itself explores what appears to be a basic shift in philosophy about best procurement policies. Of particular interest has been a policy of "second sourcing" which is widely presumed to be beneficial. It is one of the cornerstones of new policy directions. Recent regulations provide for wider use of second sourcing to reduce procurement costs following recommendations of the President's Blue Ribbon Commission (1986).

A second source can obviously compete more effectively if the technical data developed by the first source are made available prior to submitting bids in the reprocurement phase. As such technical data problems are seen to be a major obstacle in the way of competitive reprocurement (Yuspeh 1976), the regulatory response has been to call for the contracting agency's acquisition of the technical data of the contractor and require the agency to make the data available to prospective competitive suppliers for reprocurement. Since a nonnegligible fraction of government procurement is developed as a result of private research and development activity by suppliers who also operate in commercial markets, there exists a countervailing presumption that the potentially adverse effects of the policy on the incentives for private research and development may mitigate the beneficial effects of second source contracting. The problem is complex and the exact nature of costs and benefits of a policy of second sourcing remains to be studied systematically. The purpose of this paper is to integrate and experimentally test models of competition as applied to second sourcing policies. Should a presumption exist that a policy of second sourcing is generally beneficial? If it is not generally beneficial, under what circumstances is it? In particular, is the existence of private research and development, and of commercial markets important? What types of tools and theories should be applied to determine the answer to the question?

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This study is focused on two topics in government procurement problems: second sourcing, and private research and development investment in procurement. A simple theoretical framework is developed to analyze the likely effects on private R&D and procurement prices of recent proposals regarding competition in procurement and the associated data-rights policy. The framework is also used to demonstrate a major flaw in the current methodology used in the evaluation of the benefits of second sourcing. The framework can be used to identify a competition-reduction effect of second sourcing. In procurement environments where private R&D is an important factor and potential sellers have commercial markets which may be adversely affected, second sourcing may reduce competition in the initial procurement stage. Experimental methods are used to test for the existence of the effect.

The complexity of general procurement problems lead immediately to an inescapable conclusion. Policy decisions will necessarily be based on theory. In spite of the protestations of pragmatic, practical, realistic, and anti-theoretical decisionmakers, some theory, good or bad, mathematical or verbal, implicit or explicit will be behind every policy decision. The problems are complex. The variables are numerous. The data are sparce. As will be outlined in the following section, policies based on solid field experience cannot exist. Theory cannot be avoided. The only questions are which theory and how does one decide which theory?

The strategy of this research is to first outline sets of basic principles on which competing theories of procurement rest. The strategy is then to undertake many procurements under controlled laboratory circumstances in which costs, information, policies, profits, research, etc. are well defined and observable. Competing theories will be tested against data in these simple cases of procurement. If a theory works poorly in the simple cases or if it is actually misleading in the simple cases then its reliability in complex cases is automatically in question. The simple cases of experiments are proposed as test-beds for theories that are to be ultimately used to analyze very complex phenomena.

Two broad classes of theories are of relevance to procurement issues. The first theory is implicit in the standard methodology that has been applied to generate the presumption in favor of second sourcing. It involves no features of strategic behavior. The theory reflects practical decisions forced by limitations of data and the time and talent needed to incorporate more elaborate theories into empirical tools. This theory is in stark contrast to the alternative body of theory which rests upon the theory of games and strategic behavior. As it turns out the differences are of such importance that if the game theoretic approach is the correct approach then the standard methodology could lead to the wrong decision regarding second sourcing due to a bias in the way data is interpreted.

The experiments reported in the body of the paper focus directly on the issue of proper theory. The first question asked is which body of theory best explains what is observed in the simple experiments? Since the theories will be applied to a wide range of complex circumstances accuracy in the simple cases should be a minimal expectation. If the data from the experiments suggest significant strategic behavior, then the field measurements based on the standard empirical approach could be misleading. However, existence of strategic forces does not immediately imply a verdict regarding the policy. This is because game theoretic considerations are consistent with a number of equilibrium configurations of the strategic effects. At some of these equilibria, alternative sourcing policies cannot be distinguished with regard to the procurement prices they give rise to. As there is

no compelling reason to rule such equilibria out as implausible on game theoretic grounds, experimental data can be of additional use in identifying the empirically more plausible equilibria. If the experimental observations mainly cover equilibrium situations where the sourcing rule does matter, and it matters in ways contrary to the general presumption that second sourcing will be beneficial, then the standard methodology gives biased answers to the question of which policy.

As it turns out, the last situation is the case. Principles of game theory are important and must be incorporated into policy analysis. These principles can be used to show that under a large set of plausible circumstances sole sourcing should be used over second sourcing. Furthermore, the standard methodology will bias the interpretation of the field data in favor of second sourcing. The only resolution is field work which incorporates the proper theoretical tools.

DIMENSIONS OF THE PROBLEM

The problems related to procurement involve a conjunction of some of the most difficult and challenging issues in economics. Table 1 illustrates the dimensions of the procurement policy problem and important variables in each dimension.

Formally acquisition policy is a combination of decisions along three dimensions: (1) supplier selection procedure, (2) contract type, and (3) sourcing rule. The policymaker chooses from among several mutually exclusive options and suboptions in the first column. For example the policy might be to use second price auctions, a fixed price contract, and sole sourcing. An alternative policy could involve first price auction together with cost-plus contracts and sole sourcing. It is clear that the number of potential policies is as large as the number of combinations. The performance of a given combination of decisions along these dimensions can be evaluated according to one or more of the performance criteria listed in the second column in Table 1. Again, a large number of possibilities can be seen. Each criterion can potentially yield a different evaluation and thus must be applied independently. The performance of a given policy as evaluated by a given criterion would depend on economic circumstances such as those found in the third column. The list of factors that determine the economic circumstances given in column 3 is restricted to those which have been or can readily be formalized conceptually in a theoretical model. Even with this restricted list the number of potential circumstances is large.

The question of the effects of competitive reprocurement cannot be answered on purely empirical grounds. The problems are so numerous and complicated and the number of variables involved is so large that sufficient data will never exist. Judgments based on experience alone will by necessity be inadequate. Some theory, whether it is made explicit or not, about the fundamental factors in the economic structure that underlies the procurement problem will necessarily precede any empirical effort. Any system designed to measure such a complex phenomenon must be based (explicitly or implicitly) on some theory of economic behavior. The key to proper analysis is reliable theory.

Ideally, an analytical framework would provide a classification of proper policies according to each possible criterion under any given set of factors which determine the economic environment. Lacking such an ideal map which covers the entire territory, studies of given policies under varying economic circumstances would help to clarify the systematic effects of certain factors, and uncover

underlying tradeoffs which should be taken into account in policymaking. A first stage in a proper analysis is to evaluate the theories from which broad-ranging conclusions can be drawn.

There are two broad classes of theories distinguished by their treatment of, and the emphasis they place on, incentives, strategic behavior, and information conditions. One class is game theoretical and the other class is the theory that is implicitly assumed in empirical work. The nature and the implications of incentives, information, and strategic factors constitute the main focus of modern game theoretical studies whereas the issues implied by the existence of these factors, although acknowledged, are not explicitly accounted for in empirical work in the field.

Existing game theoretical studies cover some of possibilities outlined in Table 1. The procurement problem lends itself as an application of several branches of modern economic theory. In particular, theories of auctions and contracts have focused directly on types of transactions which have many of the features that characterize the federal acquisition programs. A number of studies in this literature provide important analytical tools which can be used to incorporate strategic behavior in general models of procurement policy. For instance, there is a well-developed theoretical framework for the study of different types of auctions and contracts in economic literature (Vickrey 1961; Myerson 1981; Maskin and Riley 1984; Milgrom and Weber 1982, 1985; Harris and Raviv 1981; Riley and Samuelson 1981; McAffee and McMillan 1985a; Laffont and Tirole 1987b; Dasgupta and Spulber 1987). Additional studies are underway (Besen and Terasawa 1987a and 1987b).

A need to study sourcing rules under circumstances in which R&D is an important factor introduces a dynamic element that has special features in terms of possible strategic behavior. A proper analysis of these dynamic features calls for extensions of the tools mentioned above. Second sourcing has been studied by several authors (Anton and Yao 1987a; Demski et al. 1987; Laffont and Tirole 1987a). Demski, Sappington and Miller conclude that second sourcing is a valuable auditing tool for a regulator. Anton and Yao (1987a) and Laffont and Tirole (1987a) both examine a situation where an incumbent producer has private information on the cost of the program and gains experience during initial production. In Anton and Yao (1987a) the experience gained depends only on the size of the initial production, whereas in Laffont and Tirole (1987a) experience is the result of the incumbent's investment. Laffont and Tirole (1987a) develop a model which reveals the importance of factors which determine the investment environment for the performance of different contract types and auction rules in reprocurement. Because the model takes as given a situation where a supplier for the initial production is already selected, the effect of the policy decisions on incentives in the stage prior to selection of the initial supplier is not modeled. Riordan and Sappington (1988) in a model which takes these linkages into account conclude with a pessimistic view of second sourcing in procurement.

Private research and development, and vulnerability of prospective suppliers' commercial markets under government data-rights requirements are additional factors which may enhance the adverse effects already identified in models of second sourcing. Since data-rights requirements constitute an essential part of second-sourcing initiatives, existence and size of the prospective suppliers' private commercial markets suggest themselves as factors which may add to the "cost side" of second sourcing. In addition to and independent of the other effects, second sourcing may reduce competition in the initial phase of procurement when these features are taken into account.

The theory which lies implicitly at the foundations of empirical work is much different from the theory which stems from game theory. As Anton and Yao (1987b) observe in their survey of empirical studies on the effectiveness of competitive reprocurement, there is a "broad consensus among the studies with regard to the conceptual framework that underlies the analysis," and "a considerable gap between empirical studies on procurement and recent theoretical work in the area. The issues that are emphasized in theoretical models (informational asymmetries, strategic behavior, commitment) do not play a significant role in the empirical effort." In terms of Table 1, economic conditions, the third column, are not systematically a part of the analysis in the body of empirical studies.

The key analytical construct in the conceptual framework common to the empirical studies is the so called "learning curve" along which prices move downward with accumulated production experience. Much of empirical effort has focused on the specification and estimation of the learning curve from historical data on costs and/or prices. Most of the previous empirical studies of second sourcing in procurement employ examples, case studies, and statistical methods using historical data to get estimates of the benefits of the policy. Case studies comparing observed procurement costs before and after breakout [1] (with adjustments for "learning curve" effects to get estimates of what the price would have been had the sole-source situation been continued) seem to be the standard methodology in the evaluation of second-sourcing policy (Anton and Yao 1987b, Yuspeh 1976). This comparison typically results in the conclusion that, disregarding the direct cost of technology transfer, second sourcing results in substantial cost savings.

A METHOD OF EVALUATION

Case studies can be a basis for understanding the underlying economics but the complexity of the problems dictates a need for other sources of data. Modern laboratory experimental methods can now be very useful. Laboratory methods can be used to test the predictions of competing models of the economics of procurement and to generate a data base under controlled conditions for an empirical comparison of the relative performance of alternative policies.

Experimental Setting

The experimental focus is on private R&D decisions and procurement costs under fixed-price contracts. The contracts considered are production contracts as opposed to development contracts. Research and development is undertaken by private parties in anticipation of a subsequent production contract. The procurement cycle consists of two phases: an initial procurement and a reprocurement phase. The first phase roughly corresponds to the first three phases of the procurement cycle in the general setting of weapon systems acquisition with government-sponsored research and development: namely, initial design, development, and initial production stages. The item to be procured is either a well defined object or some well specified function to be performed so that the unit price is the only evaluation criterion used in the competition. One unit of the item is

1. "Breakout" is a term that refers to the starting of competition in a procurement program.

procured in each of the two phases.

The economic circumstances are characterized by a small number of potential suppliers, some of whom may have commercial operations parallel to government business, each having private information about cost conditions and technology. The contracts are let using sealed-bid auctions (first-price or second-price). Participants make private R&D investments prior to the procurement auction which determines what it will cost them to produce the procurement item in case they win the auction. Average private R&D levels and average procurement costs are observed over a number of independent procurement programs. The following sourcing rules are used:

1. sole sourcing (multi-year contracting)
2. second sourcing with government data rights

Sole sourcing, as we use the term, differs from the way it is used in general procurement practice. In practice, after a supplier is selected in the initial procurement phase, the contract price is renegotiated before each of the subsequent production runs start and therefore is determined through bilateral bargaining at each stage. In the experimental set up, the initial phase auction winner is paid the same price for the additional unit he produces in the reprocurement phase. This can be interpreted either as the supplier having a particular "bargaining power" in the renegotiation stage, or simply as commitment by the buyer so that renegotiation does not take place. Before the production of a second unit begins the supplier can engage in additional investment activities to further reduce his unit production cost below the level of initial phase production cost.

Under second sourcing, also called competitive reprocurement, the supplier in the reprocurement phase is determined by holding an auction for the second unit to be procured. Before the auction is held, each potential supplier may make an investment to further reduce his/her unit production cost below its level in the initial phase. The feature of government data rights is operationalized by making the technology of the initial phase supplier to all potential suppliers in the reprocurement phase, which means the reprocurement phase production cost of any potential supplier cannot be higher than the initial phase production cost of the initial phase supplier.

The participants' earnings depended on the decisions they made in two markets, Market 1 and Market 2, in a sequence of sessions. Each session consisted of two periods corresponding to the initial procurement phase and reprocurement phase, respectively. In each session twelve participants were randomly matched in four groups with three sellers in each group. Sellers in each group did not know the identities of the other two sellers in their group in any session. This was intended to prevent additional complications such as collusion and reputation building which would otherwise be more likely to arise.

In Market 1, one unit of an object was bought from one of the three potential sellers using a sealed-bid first-price auction procedure. The timing of decisions in Market 1 is given in Figure 1. A seller's unit production cost is determined as a random function of the level of investment that he/she undertakes prior to the auction. In the absence of any investment, unit production cost is some fixed number C^*. Costs could conceivably be as low as C_* as a result of the seller's decision to undertake R&D. However, the outcome of R&D is uncertain. Each unit of R&D gives rise to a production cost figure between C_* and C^* according to a fixed probability law F. The higher the R&D outlay

the more likely it is for the supplier to have a low production cost. Also, there are "diminishing returns" to R&D in the sense that each additional unit of R&D gives on average lower reduction in expected production cost. For each unit of investment the seller pays a fixed price m. The value to the buyer of each unit is some amount greater than the highest possible production cost (C^*).

There are several possible interpretations of the R&D investment in this setting. It may be interpreted as the number of independent projects pursued by the supplier to aim at the same cost-reducing innovation, as the size of the research staff hired by the firm, or as the number of lottery tickets the outcome of each being a realization of a random production cost, or simply as the size of a random sample drawn from a fixed distribution with replacement. The supplier's production cost is the lowest cost among the random outcomes of the investment units he/she has undertaken. Since the price per unit of investment is fixed at the same level for all experiments, a decision on the level of R&D intensity is equivalent to a decision on the level of R&D expenditures. The production costs are "private" in the sense that those elements of production cost which are common to all potential suppliers are, without loss of generality, normalized to zero. The randomness of the research outcomes is taken to be such that every possible level of production cost is equally likely for a each unit of investment; i.e., F is the uniform distribution on $[C_*, C^*]$.

The potential suppliers simultaneously decide the level of investment they would like to make by paying m per unit of investment. Each seller knows his/her production cost privately. After the sellers make their investment decisions the investment decisions are publicly announced in each group. Then sellers are asked to submit their bids. The seller who submitted the lowest bid in each group gets to supply one unit and is paid his/her bid for the unit. No bid above C^* is accepted in the first period.

In the second phase under sole sourcing an additional unit is bought from the sellers who won the auction in the initial phase in each of the four groups. Each of these sellers is paid his/her initial phase bid for this additional unit. The seller's second period production cost is equal to either his/her first period production cost or, if he undertakes any investment in the second phase, the minimum of the second phase research outcomes, whichever is lower.

Under second sourcing with government data rights, the procedure in the second phase is the same as in the initial phase except for the determination of second phase production costs. In this case, after the initial phase is over, the initial phase production cost of the initial phase auction winner is announced publicly in each group. The second phase production cost of each bidder is the minimum of his/her initial phase production cost and the initial phase production cost of the initial phase auction winner in his/her group, if a seller does not make any investment. Sellers can further reduce their production costs by making additional investment under the same conditions as in the initial phase. Bids for the second unit are submitted after the sellers observe their second phase production costs privately, and the investment decisions are publicly announced in each group. No bid above the initial phase production cost of the initial phase winner is accepted in the second phase.

Market 2 corresponds to the commercial market. This market has implicit demand and cost characteristics which correspond to a per period profit level of R_1 for a supplier if he/she is the only supplier, R_2 for each supplier if there are two suppliers and R_3 per supplier if there are three suppliers. These values of R_1, R_2, and R_3 are related by the fact that they correspond to the

symmetric Cournot-Nash equilibrium payoffs in a quantity setting game among one, two, and three players, respectively.

At the beginning of each session, one supplier in each group is randomly chosen to be the monopoly supplier in Market 2, and he/she is called the *incumbent*. The other two potential sellers in the group have the option of spending some "effort" to try to enter the commercial market. Whether or not these two sellers can enter the market depends on the random outcome of the R&D investment they make in Market 2. Each unit of R&D results in a "success" with probability q, and in a "failure" with probability $(1-q)$. R&D in the commercial market costs s_1 per unit. If the outcome of any investment unit undertaken by a seller is a "success" then that seller can enter Market 2, and receives a payment of R_2 or R_3 in the initial phase depending on the outcome of the investment undertaken by the remaining seller. That is, the commercial market is shared by the incumbent and the sellers whose R&D investments result in a "success." The more a seller spends on R&D the more likely it is to hit a "success," and thereby to enter the market. Sellers who enter Market 2 in the initial phase remain in Market 2 in the second phase. Sellers who could not enter in the initial phase may make an additional investment in the second phase to try to enter in the second phase. The price per unit of investment in the second phase is different under sole sourcing and second sourcing. Under sole sourcing the unit price of investment in the second phase, s_2, is the same as in the initial phase; i.e., $s_1 = s_2$. Under second sourcing with government data rights, if the seller who is the incumbent supplier in Market 2 wins the initial phase procurement auction in Market 1, it becomes "easier" for the other two sellers to enter the commercial market in the second phase, in the sense that sampling cost in Market 2 in period 2 is reduced to s_2' which is less than s_2. Otherwise, it remains the same as in period 1. If one keeps the unit cost of R&D at the same level, this is equivalent to each unit of R&D investment becoming more likely to result in a success.

The sellers make their investment decisions in the two markets simultaneously.

Experiments

A total of eight experiments were conducted. Four experiments were run under each of the two sourcing rules. In each experiment twelve subjects participated. At the beginning of each experiment the subjects were given some initial cash which they could use for investment in the two markets during the experiment.[2]

In experiments 1A, 2A, 3A, and 4A sole sourcing was used, and in 1B, 2B, 3B, and 4B second sourcing was used. In experiment set 1, experiments 1A and 1B, forty sessions of the basic design were conducted, and in each of the experiment sets 2, 3, and 4, twenty-five sessions of the basic design were conducted. Each session consisted of four parallel procurement programs on which three bidders submitted bids. Average private R&D levels and average procurement costs are observed over a number of independent nondevelopment procurement programs. Therefore, we have obtained observations on 160 independent programs under each sourcing rule in experiment set

2. All subjects were undergraduate students at California Institute of Technology. Each experiment took about two hours to complete on average. Experiments were conducted using special software at the computer network at Caltech Economics and Political Science Laboratory.

1, and on 100 independent programs under each sourcing rule in each of the experiment sets 2, 3, and 4.

In experiment sets 2, 3, and 4, the sole sourcing and second sourcing parts were run in sequence using the same pool of subjects. In experiment set 1, the sole sourcing and second sourcing parts were conducted on different dates and some of the subjects were different in the two parts. The same experimental parameters were used in each of the last three sets of experiments. The sequence of the two parts of these sets was second sourcing-sole sourcing, sole sourcing-second sourcing, and second sourcing-sole sourcing in sets 2, 3, and 4, respectively.

The parameters used in the experiments are given in Table 2. These parameters are common to all experiments. The only exception is that in experiment 1A, sole sourcing, Market 2 was not incorporated, and the values R_1, R_2, and R_3 were different from the ones in the other experiments.

Figure 2 depicts the expected production costs together with one standard deviation band around the expected cost for each level of investment expenditure. Also in Figure 2 is the mean of production costs for each level of investment expenditure based on the random numbers that were used in the experiments.

THEORIES

According to game theoretic principles, the common feature of the potentially self-defeating effects of second sourcing derive from the interaction of incentives and strategic responses of the participants. We illustrate the possible workings of strategic principles in a simple example.

An Example

Suppose two potential suppliers, say A and B, engage in private research and development activity before they enter bids in a government procurement auction. The auction winner gets to supply the item on a sole-source basis for the entire life of the program (say two periods) and gets paid his bid for the item in both periods. In Figure 1 the timing of the decisions is depicted.

A policy which makes the technology of the first period winner available to all participants in the second period will reduce the cost of reprocurement, and can be advocated on economic efficiency grounds when one evaluates such a policy in period 1. Also suppose, for purposes of the example that one of the potential sellers, say A, is the exclusive supplier of an object which uses a similar technology in a commercial market, and that it is too costly for B to try to discover A's technology in the commercial market. Again, it is intuitively clear that making A's technology available to B in the commercial market would increase price competition and lower prices in that market. It can be argued that second sourcing with data-rights provisions will achieve more competition and lower prices in A's commercial market if A is the first-period winner since the technology A uses for the procurement item reveals his technology in the commercial market.

So far, it looks as if we have a policy which gets two birds with one stone. One might think that the policy would result in lower prices in both the commercial market and the government procurement contract. However, a careful consideration of strategic responses of A and B will reveal that the policy will not only fail to improve efficiency in the commercial market but also will increase procurement cost in the government auction. The reason is that A would simply not

participate in the first period government auction if the difference between the value of being the exclusive supplier and the value of being one of two suppliers in the commercial market is sufficiently high, since winning in the first period would mean the loss of his/her commercial market in period 2, thereby leaving *B* the sole supplier in period 1. As *A* never wins in the first period he/she remains the exclusive supplier in his/her commercial market. Moreover, as *B* is the sole bidder on the government procurement contract in period 1 and he/she anticipates the competition in the reprocurement stage, he will not only bid as high as the market will bear in the first period but will also invest less in cost reduction activities since he/she expects lower returns in the second period than he/she would get under sole sourcing.

Even if the value of the commercial market is not so high as to warrant *A* 's dropping out of the procurement auction, the seller *A* would increase his bid in the first period by the amount he stands to lose in the commercial market in case he wins the auction. This, probably, is obvious. What is probably not so obvious at first sight is that seller *B* would do exactly the same because by winning the auction instead of letting *A* win in the first period he would be forgoing a share of the commercial market in the second period and, thus, his bid will reflect this foregone opportunity.

Now consider the case where both sellers have private commercial markets part of which they stand to lose if their technology is made available to others. Similar reasoning would reveal that both sellers would bid as if their production costs have increased by the full value of their commercial market, that is, by about ***twice*** the amount they stand to lose in their respective commercial markets (Güler 1988).

Implications of Game Theoretic Analysis

Second sourcing has three independent effects under circumstances where private R&D is an important factor and potential sellers' commercial markets are rendered vulnerable by data-rights requirements. The first two effects are similar to the ones discussed in the Riordan and Sappington (1988) study of second sourcing under different assumptions. The next effect is independent of the first two and is due to the existence of private commercial markets. The first two effects are closely related to the ratchet effect in the planning literature. Although this tendency to shift investment to future, until the return to investing the marginal unit now and to investing it later is equalized, exists under both rules, due to the sequential search aspect of the investment decision problem, second sourcing induces additional incentives for an agent to shift effort to the second phase where the results of such effort cannot be used against him/her. These incentives are kept in check by the existence of rivals and initial period rewards. Such incentives are nonexistent under sole sourcing.

1. Sellers would anticipate the reduction in potential profits in the future and invest less in R&D than under sole source, which gives rise to higher average cost for every potential seller.

2. For every given level of production cost for the seller, the prospect of reduced future return causes every bidder to bid less aggressively in the initial procurement stage than under sole source.

3. With data-rights provisions, sellers with commercial markets, which may be adversely affected if they win the auction in the initial procurement phase, completely drop out of the auction in the initial phase if the value of commercial operations relative to the profit they expect in the procurement market is high enough. This results in fewer sellers in the initial procurement phase and higher initial period procurement cost on average. We call this a competition-reduction effect.

   When the value of commercial operations is not high enough to warrant dropping out of the procurement market in the initial procurement phase, the sellers with commercial markets will invest less and bid less aggressively than the sellers without commercial markets. In addition to this direct reduction in competition, sellers without commercial markets, anticipating the less aggressive investment and bidding behavior of the sellers with commercial markets, may in turn bid less aggressively in the initial procurement phase than they would otherwise do. An additional incentive for the sellers without commercial markets to bid less aggressively in the initial procurement phase is that if they bid high enough so that a seller with a commercial market wins the first-period auction, they will be obtaining potential access to a valuable commercial market by obtaining the technical data in the reprocurement phase.

Although there remain important basic research problems to be solved to characterize all the possibilities under second sourcing systematically, one can specify the parameters describing the economic circumstances so that all the above effects are generated as part of equilibrium behavior.

All these effects work in the direction of increasing initial procurement costs. The question is whether or not this increase more than offsets the lower cost in the reprocurement stage.

The analysis above suggests that so long as some procurement programs involve potential sellers who engage in private R&D and have related commercial markets which may be affected adversely under the second sourcing with data-rights policy, blanket application of the policy without regard to the specific features of the program at hand may result in just the opposite of intended policy goals.

The analysis also suggests situations in which a "competition in contracting" policy may or may not be an effective policy in reducing procurement costs. Competition in contracting initiatives seems to be dominated by concerns about the number of potential sellers at date 2 in Figure 1; that is, at the reprocurement stage. In fact, this is the stated goal of government data-rights initiative: "The Government must make technical data widely available in the form of contract specifications in the interest of increasing competition, lowering costs, and providing for mobilization by developing and locating alternate sources of supply and manufacture" (Federal Register 1987). However, as the example suggests, in certain environments, the question of "when to use competition" is a crucial one. In many situations, a competition in contracting initiative designed to increase the number of potential sellers at date 0 would improve procurement costs, whereas the same initiative directed at a later stage in the procurement cycle would be self-defeating. In this connection, government data-rights policy, which is stated to be an aid to increasing competition in the reprocurement stage, would cause less competition at the initial stage when competition really counts. Although competition-in-contracting initiatives also contain measures to increase competition in the initial phase (e.g., publication of intended procurement programs in advance to direct private industry for

future procurement), these measures may be rendered ineffective by second-sourcing and government data-rights provisions.

Implications for the Standard Methodology

In view of the above discussion, if there is no reason to believe that strategic factors are either nonexistent or negligible then the empirical methodology used in measuring the effectiveness of second sourcing is seriously flawed. A proper comparison of sole-sourcing and second-sourcing policies requires data which cannot be obtained from historical sources simply because the two policies are mutually exclusive, and hence one would never directly observe *what the price would have been* under the alternative policy. Theory must be used to reconstruct from the data "what might have been" and if the theory is inadequate the conclusions from the study can be wrong.

A cross-sectional comparison of total procurement costs across programs that are similar in all "relevant" aspects except the sourcing rule is virtually impossible with field data due to the broad diversity of procurement programs. Even if such programs could be found, because of the inherent randomness in the environment, one would need a large data set of such programs to single out the systematic effects of sourcing rules before one can have any confidence on the estimates obtained.

Procurement programs studied in empirical work differ widely with respect to not only the underlying supply conditions but also the types of contracts used. Because of this and because of the mutual exclusivity of the two sourcing rules, most empirical studies had to rely on assumptions. These assumptions were used to "extrapolate" from the data on prices and/or costs in the pre-breakout phase of acquisition programs procured under second sourcing to obtain predictions for the prices that would have been obtained had these programs been sole sourced.

Standard procedure is to compare the predictions for the price that would have prevailed under sole sourcing to the price observed under second sourcing. "Saving" due to competitive reprocurement is calculated as

$$Saving = 100\ (P_{ss} - P_{2s})\ /\ P_{ss}$$

where

P_{ss} = unit price under sole sourcing

P_{2s} = unit price under second sourcing

In empirical work, P_{ss} is replaced by an estimate, EP_{ss}, based on prices (or costs) observed in the initial procurement phase. All except one of the studies surveyed in Anton and Yao (1987b) consider only unit prices in the reprocurement phase under the two policies as opposed to unit prices based on overall program costs in their estimation of savings due to second sourcing. Predictions for the reprocurement price that would have prevailed had sole sourcing continued are obtained by extrapolation from the prices (or costs) observed in the initial procurement phase.

The measure itself and the way it is estimated in empirical studies both reflect a fundamental assumption implicit in the studies:

Strategic Neutrality : in the absence of learning curve effects, the reprocurement price under sole sourcing would be approximately the same as the price in the initial procurement phase under

second sourcing. Furthermore, price in the initial procurement phase would not be systematically affected by the strategic responses of the sellers to the possibility of breakout in later phases.

The proposition is that observed magnitudes are not affected by the strategic behavior of the buyer or the sellers. The key assumption is that agents do not respond strategically to changes in the economic environment. Although this assumption is not made explicitly in all of the empirical evaluations of second sourcing, from the point of view of modern economic theory, validity of both the evaluation measure used and the way this measure is estimated from field data depends crucially on this assumption.

Violation of the assumption of strategic neutrality; i.e., existence of strategic behavior on either side of the procurement market, has important implications for the validity of both the measure used to evaluate alternative sourcing rules, and the procedures employed to get an estimate of this measure.

With regard to the strategic responses on the buyer side, first of all, the validity of the measure itself, regardless of how it is estimated, depends on the implicit assumption that quantities purchased are independent of price, that is, the buyer does not respond strategically by purchasing different quantities when faced with different prices. If, as it is generally the case, quantity purchased increases with lower prices then the benefits of lower prices are underestimated by the measure. This underestimation is a consequence of the failure of the model to incorporate behavioral and strategic responses within the procurement process.

The second implication of strategic behavior on the buyer side is for the validity of the usual practice of estimating the evaluation measure from field data on programs procured under second sourcing. Suppose the buyer decides the choice of sourcing mode in the reprocurement phase on the basis of price obtained in the initial procurement phase. For example, the buyer might introduce competition in the reprocurement phase only if the price in the initial phase is high—as is seen to be the standard practice in defense procurement (Anton and Yao 1987a). Such strategic behavior will cause the saving measure to be overestimated because of the sample selection problem.

Strategic neutrality on the seller side implies that the prices in the initial procurement phase are "not very different from those that would have prevailed if it were known that there would be no competition over the entire life of the project" (Anton and Yao 1987b). This has two implications both of which would amount to an overestimation of the benefits of second sourcing. On the one hand, the ranking of the two sourcing rules on the basis of the savings measure which is based on the reprocurement phase prices only, as opposed to total program cost over the two phases, may be exactly opposite of the ranking obtained when one considers total program costs. That is, usual saving measures employed in the empirical evaluations would be invalid. On the other hand, the practice of estimating "what the price would have been under sole sourcing" using the price or cost data on second-sourced programs would clearly be invalid.

The major criticism of the standard approach has been the paucity of data used to estimate the learning curve. Little attention has been paid to the implications of the underlying assumption implicit in this approach. In the analysis that follows we test this theoretical proposition directly, and demonstrate the implications of its violation for the accuracy of evaluation measures based on the standard empirical approach.

The programs in the experiments are identical in every aspect—same number of sellers, same research environment in terms of research costs and the inherent randomness of research outcomes, same type of contracts (fixed price), same supplier selection procedure (first-price auction), etc. One unit of the procurement item is procured in each phase. The two experiments differ only in sourcing rule. Thus, in the laboratory setting we can overcome the difficulties with field data mentioned above in attempting a cross-sectional comparison. Fixing procurement quantity in each phase, auction and contract type, and sourcing mode allow us to abstract from strategic behavior on the buyer side and focus on the implications of strategic behavior on the seller side only.

In this setting, there are no "learning curve effects." In general, learning curve effects are related to production experience gained during initial phase production: the unit production cost decreases as more production is undertaken by a supplier. Although originally offered to argue that comparison of procurement costs before and after competition is introduced in a procurement program would lead to a bias in favor of second sourcing because of "learning by doing" during the process of production (Anton And Yao 1987b), the way it is employed in empirical work "learning" is better interpreted to result from research undertaken by the supplier parallel to production rather than from mere production activity. In either case, the effect of learning would result in a cost advantage for the initial supplier over the potential competitors in the reprocurement phase. In the setting we consider learning curve effects are nonexistent in either sense. Also, the direct costs of technology transfer to the second source (technology transfer, duplicated capital, start-up costs) are taken to be zero. This is certainly the most favorable setting for second sourcing in terms of the factors held to be of fundamental importance in empirical analyses.

PREDICTIONS AND EXPERIMENTAL RESULTS

Multiplicity of equilibria is a common feature of the type of procurement environments where private investment is undertaken prior to the auctioning of contracts. Existence of multiple equilibria under either sourcing rule makes it difficult to obtain point predictions on some magnitudes of interest. Also, the equilibrium comparison of the two sourcing rules becomes dependent on the choice of equilibria under the two rules. Most of the predictions below depend on the assumption of symmetric equilibrium behavior, although at some asymmetric equilibria the predictions may be reversed. However, deviations from symmetric equilibrium behavior seems not to be large enough to affect general qualitative predictions significantly.

Four series of qualitative predictions on various observable magnitudes based on considerations of strategic behavior under the conditions characterized by the experimental parameters are presented.[3] The first set of predictions are on the comparative procurement price paid by the buyer under the two sourcing rules.

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3. We do not intend these different predictions and tests as independent evidence on the relative merits of the two sourcing rules, but as an indication of the general principles discussed above in organizing various aspects of the experimental observations in a coherent whole. Due to obvious dependencies among the propositions involved a joint test of all the hypotheses would have less "power" than indicated by separate tests.

1.a Initial phase procurement price is lower under sole sourcing than under second sourcing.
1.b Reprocurement phase procurement price is higher under sole sourcing than under second sourcing.
1.c Average procurement price over the two phases is lower under sole sourcing than under second sourcing.

Figure 3.0 summarizes the above predictions. Figures 3.1 to 3.4 give the estimates for A, B and C obtained from two experiments in experiment sets 1 through 4. In each panel, prices in the initial procurement phase and in the reprocurement phase are averaged over 100 (160 for experiment set 1) independent nondevelopment programs. In the left panels in Figures 3.1 to 3.4, the average price under sole sourcing is given, and in the right panel average prices in the initial procurement phase and in the reprocurement phase are given: although average reprocurement price is lower under second sourcing, this reduction in reprocurement price is more than offset by the increase in the initial procurement prices.

Figures 4.1 through 4.4 contain the time series of average procurement prices over the two phases under the two sourcing rules. Each data point is the mean price of four independent programs.

Table 3 contains t-statistics for the null hypotheses that mean value of the initial phase, reprocurement phase, and average price under sole sourcing is equal to the mean value under second sourcing for four sets of experiments. Each of these null hypotheses is rejected in favor of the corresponding alternative hypotheses in the predictions above.

Table 4 contains the Mann-Whitney-Wilcoxon statistics for the null hypotheses that the distribution of initial phase, reprocurement phase and average prices under sole sourcing is the same as the distribution of corresponding prices under second sourcing. These statistics are normally distributed under the corresponding null hypotheses. The results support the above predictions interpreted in the first order stochastic dominance sense.

Next, we present similar predictions on the investment expenditures under the two sourcing rules. These predictions, in addition to being of independent interest as direct implications of strategic principles, also help explain the regularities observed when we looked at the procurement prices above.

2.a Initial phase investment expenditures are higher under sole sourcing than under second sourcing.
2.b Reprocurement phase investment expenditures are lower under sole sourcing than under second sourcing.
2.c Average investment expenditure over the two phases is higher under sole sourcing than under second sourcing.

Prediction 2.b follows from the fact that expected investment level in the second phase is decreasing in the initial phase investment level at equilibrium and that initial investment level is higher under sole sourcing. However, for any given level of total investment over the two phases, the buyer would prefer more of it undertaken in the initial phase.

Figures 5.1 through 5.4 contain the time series of average investment expenditures over the two phases, and Figures 6.1 through 6.4 contain the time series of investment expenditures in the initial procurement phase.

In Table 5 the statistics for testing significance of the difference between corresponding investment expenditures under the two sourcing rules are given. In general, the signs of the t–statistics are in agreement with the corresponding predictions. However, the difference is statistically insignificant in experiment set 1.

Results based on the nonparametric tests in Table 6 are also in conformity with t-tests in Table 5.

The last set of predictions and tests concern comparative investment and bidding behavior of sellers with commercial markets and those without commercial markets under each sourcing rule. Although it is not possible to isolate the workings of different factors which are discussed under effect 3 above in the observed bidding behavior of the sellers with commercial markets, the combined effect of all these factors is in the predicted direction.

Given the experimental parameters , equilibrium investment level is zero in Market 2 when the sampling cost is s_1. When sampling cost in Market 2 is s_2', there is positive investment by the nonincumbents in equilibrium which implies a positive expected loss to the incumbent if he wins the auction in the initial phase. That is, existence of commercial markets introduces an asymmetry between the initial phase behavior of the two seller types under second sourcing. This observation is the basis of thefollowing set of qualitative predictions:

3.a Under sole sourcing, initial phase bidding behavior of sellers with commercial markets does not differ significantly from that of sellers without commercial markets.

3.b Under second sourcing , sellers with commercial markets bid higher in the initial phase than the sellers without commercial markets.

3.c Under second sourcing, reprocurement phase bidding behavior of sellers with commercial markets does not differ significantly from that of sellers without commercial markets.

4.a Under sole sourcing, initial phase investment behavior of sellers with commercial markets does not differ significantly from that of sellers without commercial markets.

4.b Under second sourcing, sellers with commercial markets invest less in the initial phase than the sellers without commercial markets.

4.c Under either sourcing rule, reprocurement phase investment behavior of sellers with commercial markets does not differ significantly from that of sellers without commercial markets.

Experimental results in general agree with these predictions. Panels A in Figures 7.1.B through 7.4.B contain the time series of average initial phase bid by the four sellers who have commercial markets, and Panels B contain the time series of initial phase bids by eight sellers without commercial markets. Table 7 contains nonparametric test statistics for testing the null hypothesis that the distribution of corresponding bids is the same for both types of sellers. As predicted one cannot reject the null hypothesis of same bid distribution for the cases predicted, namely initial phase under sole sourcing, and reprocurement phase under second sourcing. The null

hypothesis that initial phase bid distribution is same for both type of sellers under second sourcing is rejected in favor of the alternative hypothesis that sellers with commercial markets bid less aggressively than those without commercial markets. The following comparison of initial phase investment expenditures across the two seller types provides an explanation for this phenomenon, namely, that sellers with commercial markets invest less in the initial phase and thus have higher production costs.

In Panels A in Figures 8.1.B through 8.4.B, time series of average initial phase investment expenditures by the four sellers with commercial markets is presented. Panels B contain the same data for the eight sellers without commercial markets. Nonparametric test statistics for the null hypotheses that the corresponding distributions of initial and reprocurement phase investment expenditures by sellers with and without commercial markets do not differ significantly are given in Table 8. Again, predictions concerning the distribution of reprocurement phase investment expenditures are consistent with the test results. Regarding the predictions concerning the initial phase investment behavior, we cannot reject the hypothesis that the distribution of investment by sellers with commercial markets and those without is the same under second sourcing for experiment 1. For experiments 2, 3, and 4 the null hypothesis that the two distributions are the same is rejected in favor of the alternative hypothesis which corresponds to the predictions. In experiments 2 and 3 , under sole sourcing, the null hypothesis that the distribution of initial phase investment expenditures is the same for both types of sellers is rejected in favor of the alternative hypothesis that sellers with commercial markets invest more in the initial phase than the other sellers.

A Test of Standard Methodology

In view of the analysis above, the assumption of strategic neutrality is clearly violated. The experimental data indicate the existence of the effects predicted by game theoretical models but are implicitly assumed to be nonexistent by the standard methodology. If the effects are on the order of the magnitude predicted by theory then we know that empirical methods must be changed to accommodate the existence of these effects. As will be shown below the effects are sizable enough to cause applications of the standard methodology to lead to the wrong decision regarding the benefits of second sourcing relative to sole sourcing.

The purpose of this section is to assess the accuracy of the standard methodology for measuring the success of competitive reprocurement. The strategy is to apply the standard methodology to the procurement and reprocurement activities that were created under laboratory conditions. Estimates of procurement price saving due to competitive reprocurement as opposed to sole sourcing were obtained from the methodology. These estimates were then compared to the measures based on actual prices which were directly observable by virtue of the controlled conditions. One major conclusion can be drawn from the exercise: the standard methodology should not be applied indiscriminately. Under certain conditions the methodology can lead to errors.

The exercise exposed two different errors. The first was in the measurement of overall program cost, which is the proper measurement for program evaluation. The actual effect of second sourcing was to increase program cost by about 40 percent over the cost of sole sourcing. Estimates based on the standard methodology were substantially in error. According to these estimates second

sourcing led to a reduction of about 30 percent in program cost instead of the actual increase.

The second error involved the narrower issue of reprocurement prices. The standard methodology led to the estimate that price in the reprocurement phase would be reduced by over 60 percent from what would have prevailed under sole sourcing. In fact the reprocurement prices were only 30 percent lower. Thus the standard methodology led to an answer that was off by a factor of two. Of course this error is related to the first since overly optimistic estimates of prices at the reprocurement phase are weighed with the impact of second sourcing in earlier phases in the calculation of the overall program cost.

In Figure 3.0, the assumption of *strategic neutrality* above amounts to the claim that $A = B$. The assumption is that price under sole source (A) would have been the same as the price for the initial phase of second sourcing (B).

Figures 3.1 to 3.4 give the estimates for A, B, and C obtained from experiments sets 1 through 4. Although average reprocurement price is lower under second sourcing, this reduction in reprocurement price is more than offset by the increase in the initial procurement prices.

A number of observations on the validity of the standard procedure in empirical evaluations of competitive reprocurement can be made using the data from the experiments:

1. Even when one considers only the reprocurement prices under the two sourcing rules as the basis for evaluation, the procedure used in empirical studies gives a systematic overprediction of savings due to competitive reprocurement. The estimates of price reduction in the reprocurement phase are given in the left panels in Figures 9.1 through 9.4. Following the standard model (strategic neutrality) these estimates are based on the assumption that, under sole sourcing, the reprocurement price would be the same as the price observed in the initial phase (since there are no learning curve effects in the experimental set up and all programs use fixed price contracts). According to these measures second sourcing reduces reprocurement cost by about 65 percent on average. If, however, actual reprocurement cost under sole sourcing is used in the savings measure, reprocurement price reduction due to second sourcing is about 30 percent (panels B in Figures 9.1 through 9.4). That is, the procedure used in empirical studies gives an estimate of savings more than twice the actual reprocurement price reduction.

2. When one considers the total program costs under the two policies (Figures 10.1 through 10.4), the distortion is even more dramatic. Using the standard procedure, one gets an estimate of over 30 percent reduction in unit prices over the entire life of the programs (panels A in Figures 10.1 through 10.4), whereas using actual average cost obtained under sole sourcing, one concludes that second sourcing increases procurement cost by over 40 percent on average.

Table 9 and Figures 11.1 through 11.4 summarize the evaluations based on the two procedures. Panels A in the figures summarize the results of applying the standard methodology to measure the effect of competitive reprocurement on:

I. initial procurement price,

II. reprocurement price, and

III. unit price over the entire program life.

In the right panels , the same measures are obtained by using actual price data under sole sourcing. Comparison across the panels also reveals the culprit for the distortion. It is the assumption of strategic neutrality above. If measurements are based on the theory implied by this assumption then these measurements necessarily overestimate the effectiveness of second sourcing and can clearly give the wrong qualitative conclusion. In fact the wrong answer is given in an environment which is most favorable to second sourcing according to the theory which underlies this methodology. Using the implicit theory of procurement that underlies this methodology one would conclude that second sourcing significantly reduces procurement costs whereas the actual fact is that it does exactly the opposite.

CONCLUSIONS AND CAVEATS

As Anton and Yao (1987b) point out "the first priority for empirical work is to identify some of the fundamental properties of the underlying economic structure of the procurement problem." The issues studied in modern theoretical models (strategic behavior, informational asymmetries, etc.) are among those fundamental features of the economics of procurement. Experimental data clearly demonstrate that the effects of these factors are real, and that theories which incorporate these factors as fundamental features of the procurement problem help us understand the systematic differences observed in laboratory markets. Theories which assume these factors to be insignificant have no explanation for the observations.

Previous studies of second sourcing in the procurement context (Anton and Yao 1987a; Riordan and Sappington 1988; Rob 1986; Demski et al. 1987) have identified several effects which determine "costs" and "benefits" of second sourcing.

On the benefit side one has the three effects discussed in Riordan and Sappington (1988).

1. Price reduction effect: second sourcing reduces reprocurement cost.

2. Production enhancement effect: second sourcing allows production which would not occur under sole source. This effect works as in Demski et al. (1987) through enhancing the auditing capability of the buyer. This effect does not exist in the experimental setting since the quantity decisions are exogenously fixed in both phases of procurement.

3. Production diversion effect: production is undertaken by different producers.

On the cost side one has

1. direct cost of transferring technology: this is the only cost considered in the empirical evaluations discussed above. In our setting we assumed it to be zero.

Next we have effects due to the "linkages" between the phases of the procurement cycle and the strategic responses of the participants:

2. R&D reduction effects: this is present in the context of both private R&D, as we have considered, and government sponsored R&D as in Riordan and Sappington (1988).

3. Competition reduction effects
   a. Bidding behavior: second sourcing results in less aggressive bidding in the initial procurement phase.

   b. Number of bidders: second sourcing may cause some potential sellers to drop out in the initial procurement phase.

How effective a policy second sourcing in general is will depend on the relative importance of the effects on the cost and benefit side of the policy. These will in turn depend on the relative importance of factors which cause these effects in the economic environment surrounding a particular procurement program. More basic research in economic theory can give insight into the finer details of the tradeoffs involved in the policy decision. Before a general economic theory of procurement policy incorporating all the relevant factors can be attempted, basic research on specific issues in the theories of auctions, contracts, and game theory is needed.

To the extent that private R&D activity and the linkages between the commercial markets of potential sellers and the procurement market are essential features of given procurement programs, second sourcing is more likely to be a self-defeating policy. However, the extent and importance of private R&D and linkages to the commercial markets in the economic environment of a particular program cannot be assessed without empirical studies.

Economic theory and experimental studies cannot go further than identifying the potential cost and benefit effects and the underlying factors which determine these effects, and testing whether these effects are "real" in the sense that they can be observed in simple laboratory environments where the underlying factors suspected to give rise to these effects are present. The final judgment on the effectiveness of a given policy for a given class of procurement programs would require empirical investigation of the existence and importance of these factors in the economic environment of the given procurement programs.

However, even with limited study, what could be a deep organizational problem within current policy can be identified. Within a given procurement program, there is always incentive for the procuring agency to "break out" in the reprocurement stage if the decision on whether or not to break out is made and announced *after* the initial procurement stage is complete. When such

surprises are introduced, breakout will lower the *cost of reprocurement* below that which would otherwise occur. However, this potential lack of systematic commitment to process can be an impediment to increased competition and private R&D in the initial procurement stage. The fear of breakout operates much the same as second sourcing in the example and is derived from a governmental and organizational environment, where procurement agencies are encouraged to achieve a cost reduction for the *remaining part* of that particular program. The fact that agencies are evaluated on the basis of the number of programs in which they "compete," and "how much they reduce reprocurement costs" without regard to the way competition is introduced or the way that cost reductions are achieved are signals of the problem. The proper perspective to be used in evaluating policies is that of date zero in Figure 1 so that the effects of a policy on private R&D decisions and bidding behavior in the initial procurement phase is fully accounted for.

While existing knowledge is far from complete, one conclusion is clearly emerging. Policies must reflect the diversity of acquisition programs in terms of the nature and size of the item being procured and the structure of the markets in which potential suppliers operate. Any policy based on the insights from a general theory which do not explicitly account for the idiosyncracies of particular acquisition programs could involve considerable costs if applied indiscriminately to all acquisition programs.

The choice of assumptions allows identification of the qualitative effect of the chosen aspects of the economic circumstances on the performance of sourcing rules in a simple framework. For example, fixed-price contracts allow us to abstract from a host of additional problems such as characterization of the optimal contracts and characterization of auditing rules. Under the information conditions assumed (bidders know their production costs before they enter their bids) fixed-price contracts lead to efficient resource allocations. Under alternative information conditions and under contract types optimal for those conditions, second sourcing may be a valuable auditing device to discipline the seller (Demski et al. 1987; Anton and Yao 1987a) and this is an important effect on the benefit side of second sourcing. Since the aim of this study is to identify effects independent of and in addition to the ones already discovered in literature, the simplest framework was chosen for this purpose. Once we identify all the important potential effects, judging the relative importance of these effects for a given class of procurement programs would be the subject of empirical investigations on the existence and relative magnitude of economic factors which give rise to these effects.

Only two alternative policies were considered in this study. Therefore, the possibility exists that when one expands the set of policy alternatives to include combinations of policy options in other dimensions, a slightly altered policy of second sourcing might fare better. For example, sole sourcing together with cost plus incentive contracts auctioned via a first price auction with a reserve price p^* could be considered along with second sourcing together with fixed price contracts auctioned via a second price auction with reserve price p^{**}. It is conceivable that second sourcing might be an essential part of the optimal procurement policy mix in certain economic environments. For a comparison of the best the buyer can do with second sourcing and the best he/she can do with sole sourcing when the options in other dimensions of the policy mix are chosen optimally, one needs a much more general analytical framework. Towards such a general framework, the present framework can be extended to cover variable quantities, optimal choice of the auction procedure and

the reserve price, and rules of reimbursement for research and development. The framework can also be extended to cover different specifications of research and development activity. These extensions are done in Güler (1988) for the one-stage version of the problem.

TABLE 1: Dimensions of the Procurement Problem

Policy Options	Performance Criteria	Economic Circumstances
• Supplier Selection Procedure – Auctions – Sealed Bid – First Price – Second Price – Negotiation	• Cost – to Seller – to Buyer – to Society	• Number of Potential Suppliers
	• Quality	• Nature of Program – Size – Development or nondevelopment
• Contract Type – Fixed Price – Cost plus Fixed Fee – Cost plus Incentive	• Timeliness	
	• Research Level	• Information Conditions
	• Time Perspective – Long Run – Short Run	• Cost Dependence – Private Costs – Common Costs
• Sourcing Rule – Sole Source (Multi-Period Procurement) – Second Sourcing – Data-Rights Rule – Government Requirement of Data Rights – Private Data Rights		• Research Environment – Research Costs – Externalities – b/w Markets – b/w Suppliers
		• Existence of Commercial Markets for Potential Suppliers
		• Possibility of Commitment
		• Duration of the Seller-Buyer Relationship – Repeated – One-shot
		• Possibility of Subcontracting

TABLE 2: Experimental Parameters

Market 1								
Experiment	I.A	I.B	II.A	II.B	III.A	III.B	IV.A	IV.B
m	16	16	16	16	16	16	16	16
C_*	0	0	0	0	0	0	0	0
C^*	5000	5000	5000	5000	5000	5000	5000	5000
Market 2								
Experiment	I.A	I.B	II.A	II.B	III.A	III.B	IV.A	IV.B
s_1	0	250	250	250	250	250	250	250
s'_2	0	50	250	50	250	50	250	50
R_1	0	5000	2500	2500	2500	2500	2500	2500
R_2	0	2222	1111	1111	1111	1111	1111	1111
R_3	0	1250	625	625	625	625	625	625
q	0	.10	.10	.10	.10	.10	.10	.10

TABLE 3: Average Procurement Price Under Sole Sourcing and Second Sourcing

	Sole Sourcing	Second Sourcing	Difference	t*	dof**
		Experiment I			
Initial Phase Mean	.11463	.25484	−.14022	−9.86187	180
Standard Deviation	.04984	.17063	.01422		
Reprocurement Phase Mean	.11463	.08169	.03293	4.43830	261
Standard Deviation	.04984	.07854	.00742		
Average	.11463	.16827	−.05364	−5.73203	219
Standard Deviation	.04984	.10602	.00936		
		Experiment II			
Initial Phase Mean	.10906	.22719	−.11813	−10.82688	152
Standard Deviation	.05196	.09594	.01091		
Reprocurement Phase Mean	.10906	.07589	.03317	3.82727	183
Standard Deviation	.05196	.06935	.00867		
Average	.10906	.15154	−.04248	−4.82577	181
Standard Deviation	.05196	.07105	.00880		
		Experiment III			
Initial Phase Mean	.10347	.21734	−.11387	−6.21316	115
Standard Deviation	.05043	.17619	.01833		
Reprocurement Phase Mean	.10347	.07208	.03140	4.33063	197
Standard Deviation	.05043	.05209	.00725		
Average	.10347	.14471	−.04123	−3.74216	148
Standard Deviation	.05043	.09797	.01102		
		Experiment IV			
Initial Phase Mean	.10684	.21306	−.10622	−8.96716	124
Standard Deviation	.04050	.11131	.01185		
Reprocurement Phase Mean	.10684	.08427	.02257	3.05708	170
Standard Deviation	.04050	.06173	.00738		
Average	.10684	.14866	−.04182	−4.98963	154
Standard Deviation	.04050	.07338	.00838		

* $t = t$-statistic for the null hypothesis that the mean price under sole sourcing is the same as the mean price under second sourcing.

** dof = degree of freedom.

TABLE 4: Comparison of Procurement Prices under Sole Sourcing and Second Sourcing*

Experiment	Initial Procurement Price	Reprocurement Price	Total Program Cost
I	–10.20840	6.77467	–15.00799
II	–9.89821	5.38331	–5.46132
III	–7.24502	4.30339	–3.21941
IV	–8.85325	3.19173	–4.45957

* The table entries are the Mann-Whitney-Wilcoxon statistics for the null hypothesis that the distribution of prices is the same under the two sourcing rules.

TABLE 5: Average Investment Expenditure Under Sole Sourcing and Second Sourcing

	Sole Sourcing	Second Sourcing	Difference	t*	dof**
		Experiment I			
Initial Phase Mean	.06402	.05918	.00484	1.87096	309
Standard Deviation	.02189	.02402	.00259		
Reprocurement Phase Mean	.00814	.00695	.00119	.73987	302
Standard Deviation	.01295	.01541	.00160		
Average	.03608	.03307	.00301	2.06932	304
Standard Deviation	.01192	.01386	.00146		
		Experiment II			
Initial Phase Mean	.09264	.07494	.01770	4.27923	183
Standard Deviation	.02479	.03310	.00414		
Reprocurement Phase Mean	.00390	.00938	−.00547	−4.29721	183
Standard Deviation	.00762	.01020	.00127		
Average	.04827	.04216	.00611	3.02066	191
Standard Deviation	.01289	.01560	.00202		
		Experiment III			
Initial Phase Mean	.05946	.04349	.01597	6.71524	193
Standard Deviation	.01803	.01550	.00238		
Reprocurement Phase Mean	.00374	.01181	−.00806	−5.14664	150
Standard Deviation	.00732	.01385	.00157		
Average	.03160	.02765	.00395	2.86294	197
Standard Deviation	.00955	.00997	.00138		
		Experiment IV			
Initial Phase Mean	.05818	.04211	.01606	10.43721	171
Standard Deviation	.00846	.01285	.00154		
Reprocurement Phase Mean	.00278	.01325	−.01046	−5.91067	134
Standard Deviation	.00706	.01627	.00177		
Average	.03048	.02768	.00280	2.35694	145
Standard Deviation	.00533	.01062	.00119		

* $t = t$-statistic for the null hypothesis that the mean investment level under sole sourcing is the same as the mean investment level under second sourcing.

** dof = degree of freedom.

TABLE 6: Comparison of Investment Expenditure under Sole Sourcing and Second Sourcing*

Experiment	Investment in the Initial Phase	Investment in the Reprocurement Phase	Total Investment
I	2.29669	0.97559	2.73797
II	4.17268	–5.25278	3.30622
III	6.32588	–4.81175	2.75867
IV	8.36369	–5.55682	3.50395

* The table entries are the Mann-Whitney-Wilcoxon statistics for the null hypothesis that the distribution of investment levels is the same under the two sourcing rules.

TABLE 7: Comparison of Bids by Sellers with Commercial Markets and Sellers without Commercial Markets*

Experiment		Initial Phase	Reprocurement Phase
I	Sole Sourcing	—	—
	Second Sourcing	2.09819	.93792
II	Sole Sourcing	−.39959	—
	Second Sourcing	6.62848	1.15662
III	Sole Sourcing	1.11629	—
	Second Sourcing	7.07268	.06001
IV	Sole Sourcing	−1.27365	—
	Second Sourcing	9.33119	−.30642

* The table entries are the Mann-Whitney-Wilcoxon statistics for the null hypothesis that the distribution of bids is the same for both types of sellers.

TABLE 8: Comparison of Investment Expenditure by Sellers with Commercial Markets and Sellers without Commercial Markets*

Experiment		Initial Phase	Reprocurement Phase
I	Sole Sourcing	—	—
	Second Sourcing	.43935	.24646
II	Sole Sourcing	2.86117	.20028
	Second Sourcing	−5.93706	1.68773
III	Sole Sourcing	.75204	1.35222
	Second Sourcing	−8.05576	−.39806
IV	Sole Sourcing	2.50369	−.31675
	Second Sourcing	−10.16891	.07536

* The table entries are the Mann-Whitney-Wilcoxon statistics for the null hypothesis that the distribution of investment levels is the same for both types of sellers.

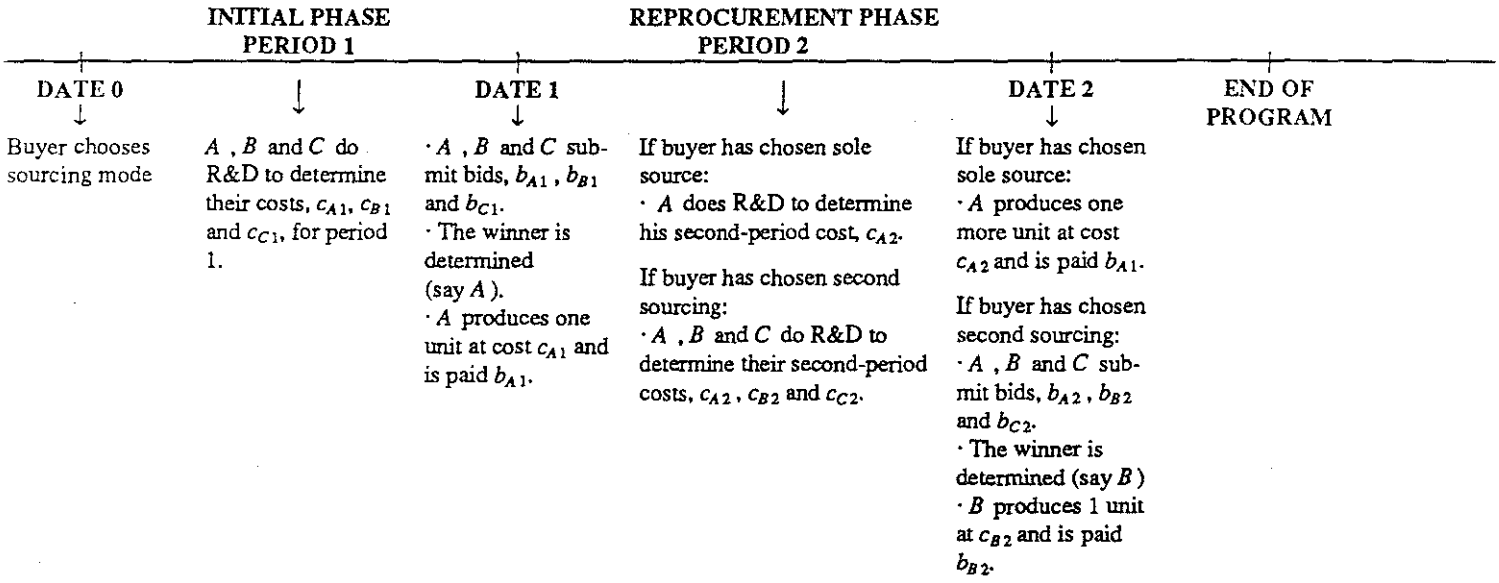
TABLE 9: Evaluation of the Effect of Second Sourcing on Procurement Cost: Percentage Price Change Due to Competitive Reprocurement

(A) Estimates Based on the Standard Methodology
(B) Actual

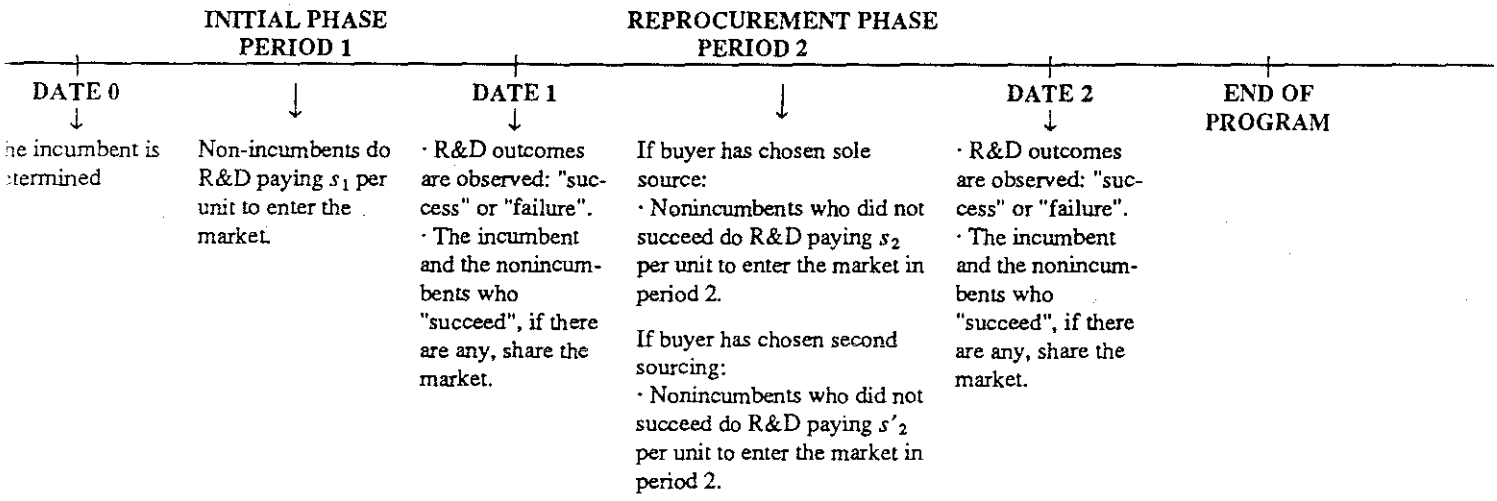
Experiment		Inital Procurement Phase	Reprocurement Phase	Total
I	A	0.0000	–0.6794	–0.3397
	B	1.2232	–0.2873	0.4679
II	A	0.0000	–0.6659	–0.3330
	B	1.0832	–0.3041	0.3896
III	A	0.0000	–0.6684	–0.3342
	B	1.1004	–0.3035	0.3985
IV	A	0.0000	–0.6043	–0.3021
	B	0.9932	–0.2112	0.3910

FIGURE 1 : Timing of Events

MARKET 1



MARKET 2



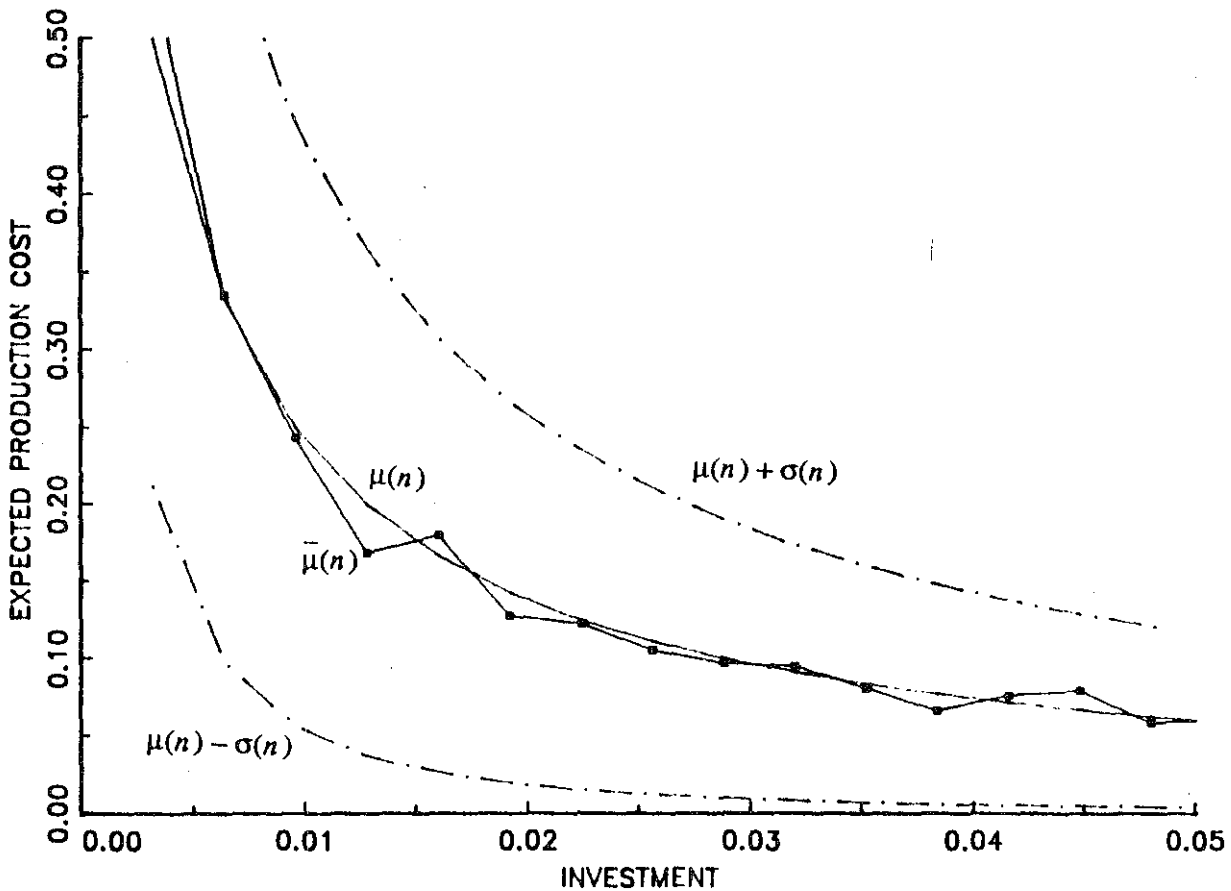


FIGURE 2 : Expected production cost as a function of investment ($\mu(n)$) and expected production cost based on the random numbers used in the experiments ($\bar{\mu}(n)$)

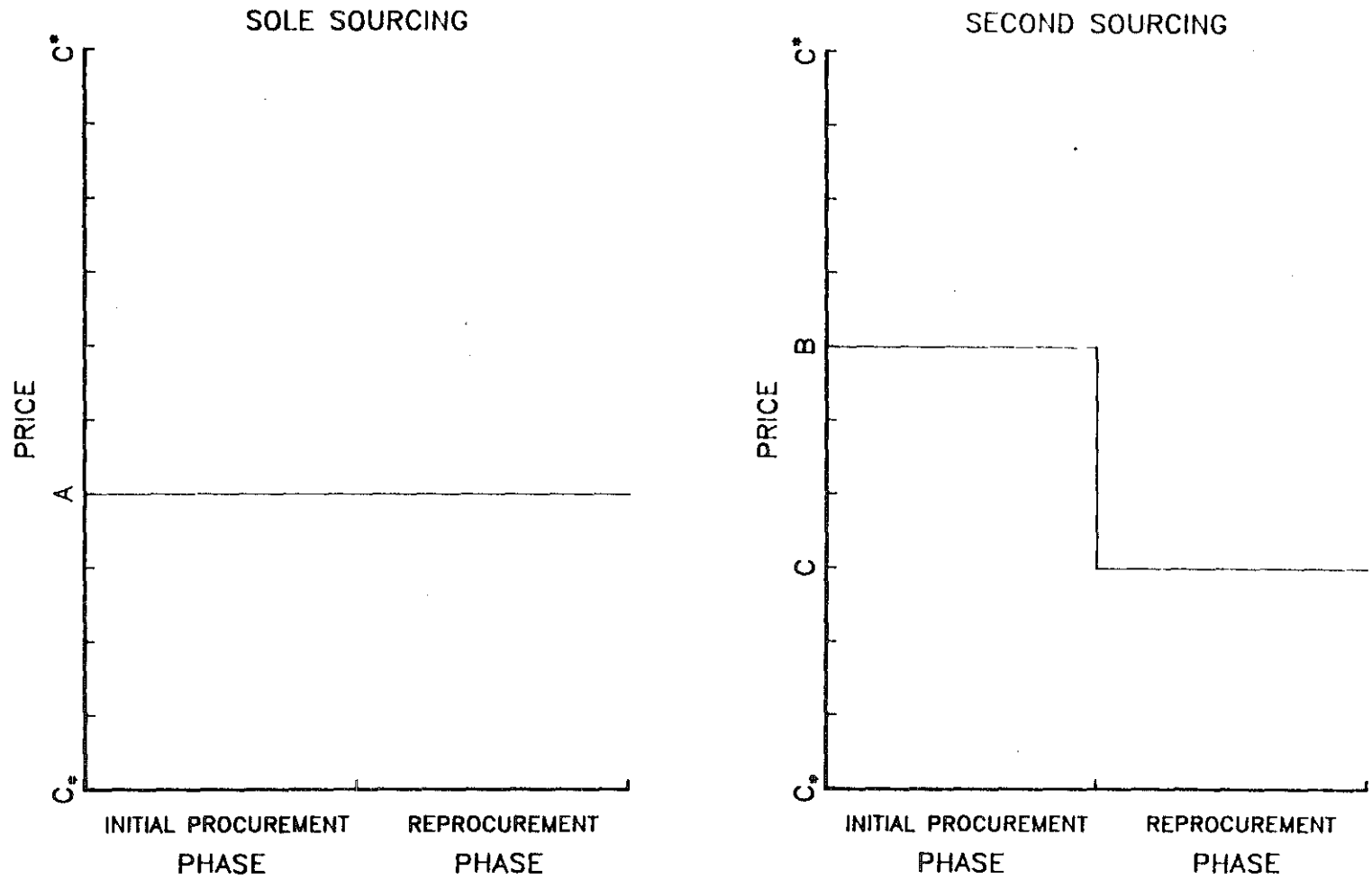


FIGURE 3.0 : Time profile of prices under sole sourcing and second sourcing (Hypothetical)

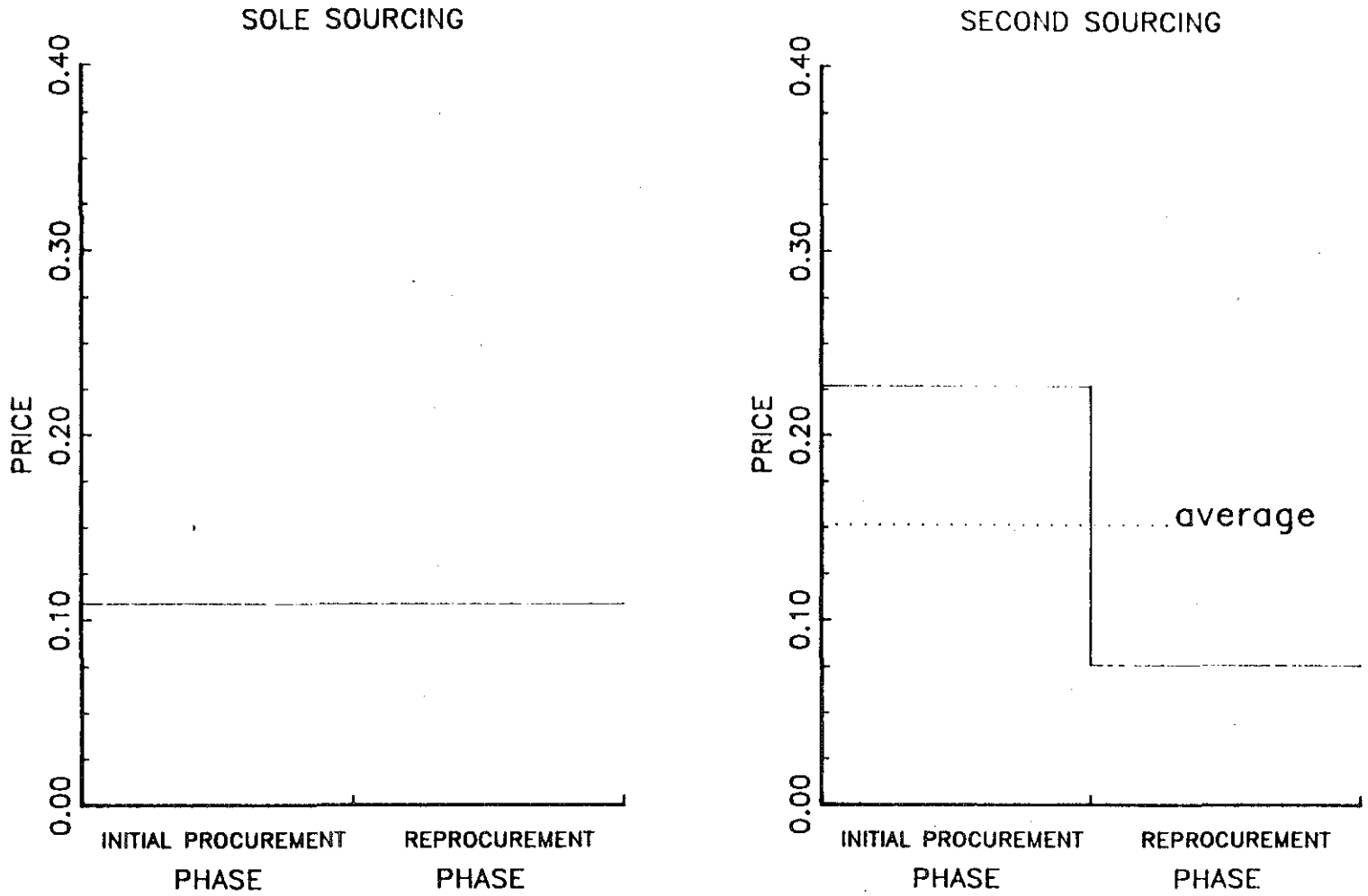


FIGURE 3.2 : Experiment 2 - Time profile of prices ($C_* = 0, C^* = 1$)

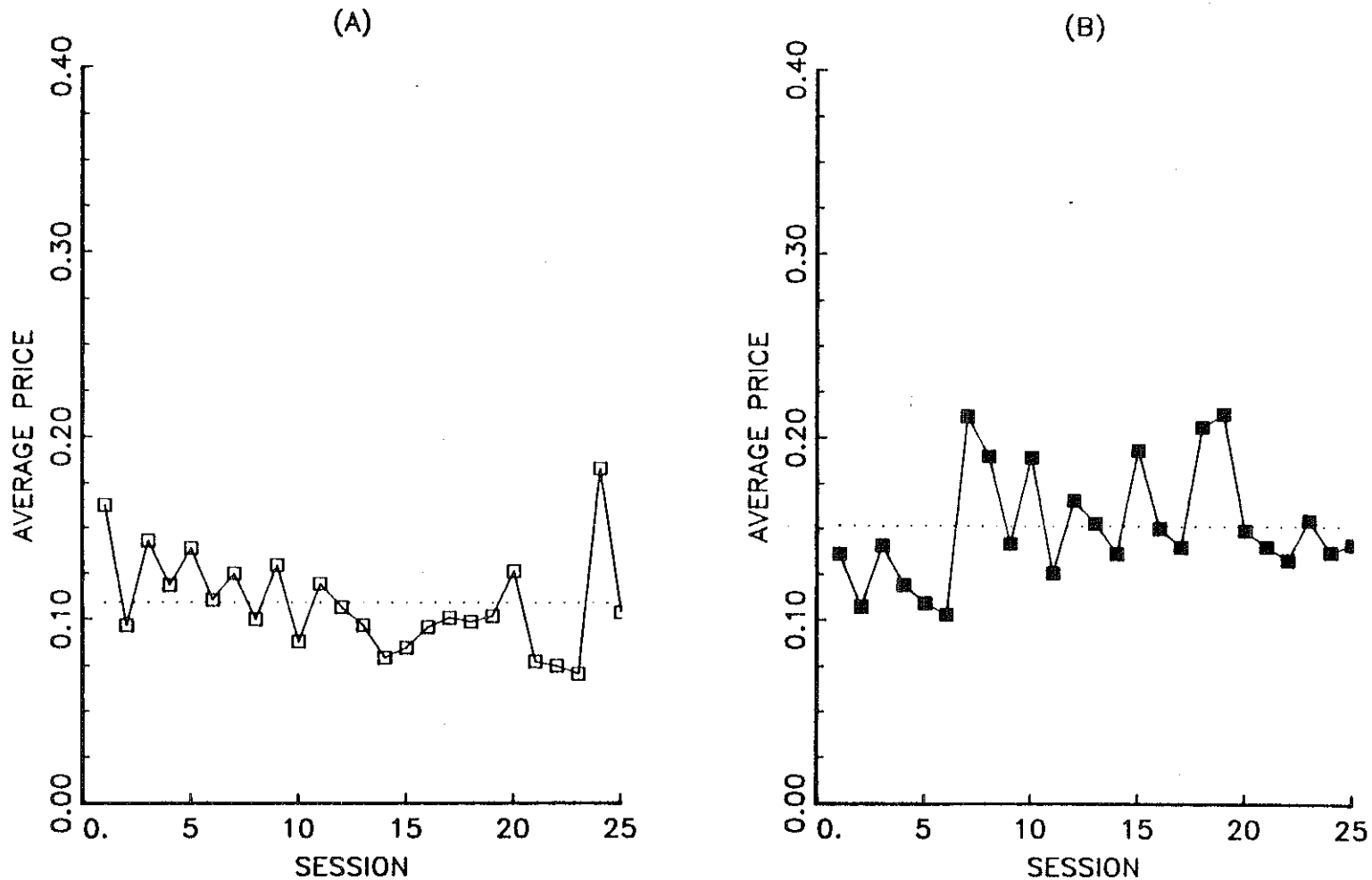


FIGURE 4.2 : Experiment 2 - Average procurement price ($C_* = 0, C^* = 1$)
A) Sole sourcing, B) Second sourcing with government data rights

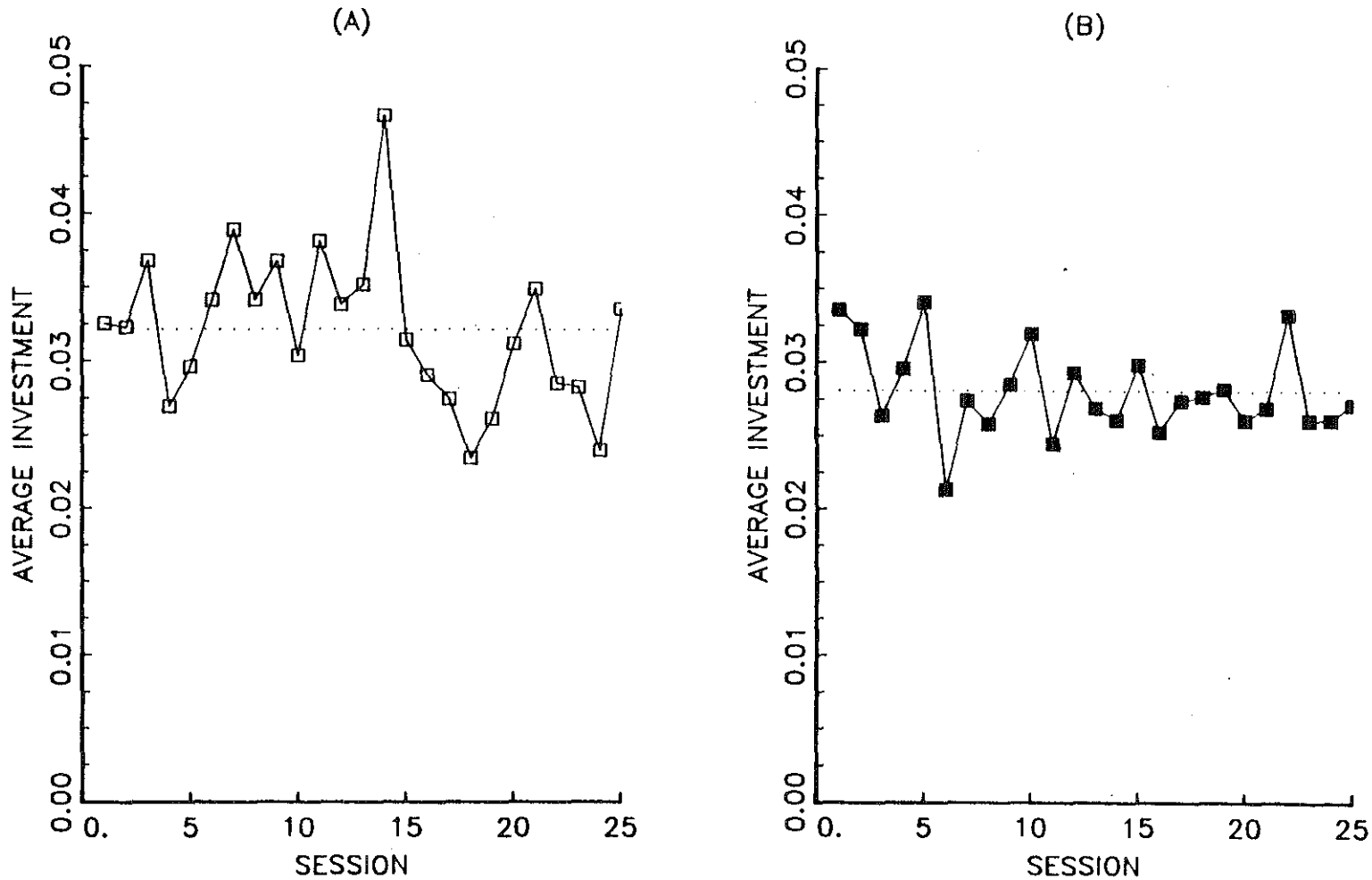


FIGURE 5.2 : Experiment 2 - Average investment expenditure
A) Sole sourcing, B) Second sourcing with government data rights

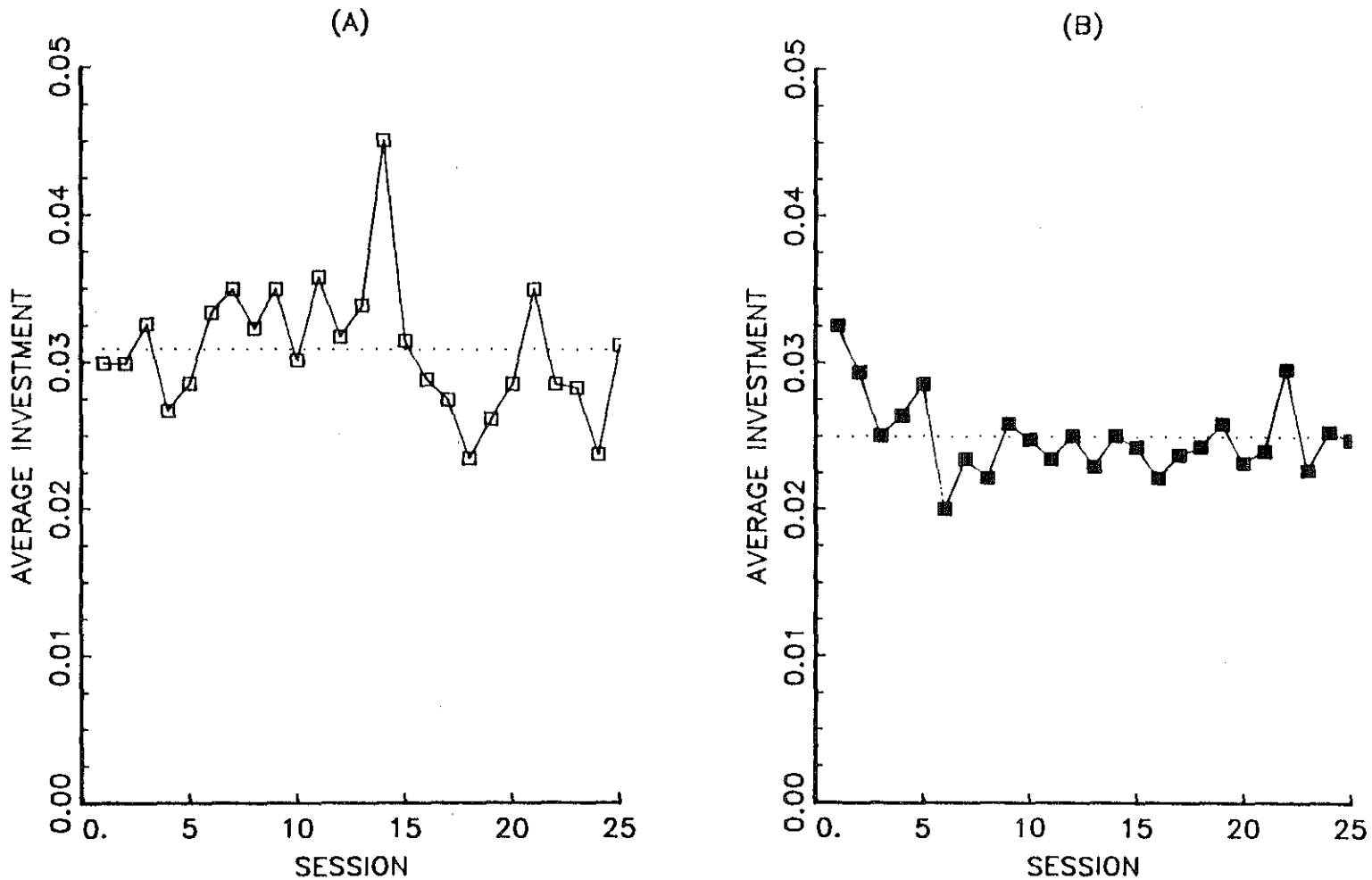


FIGURE 6.2 : Experiment 2 - Average investment expenditure (initial phase)
A) Sole sourcing, B) Second sourcing with government data rights

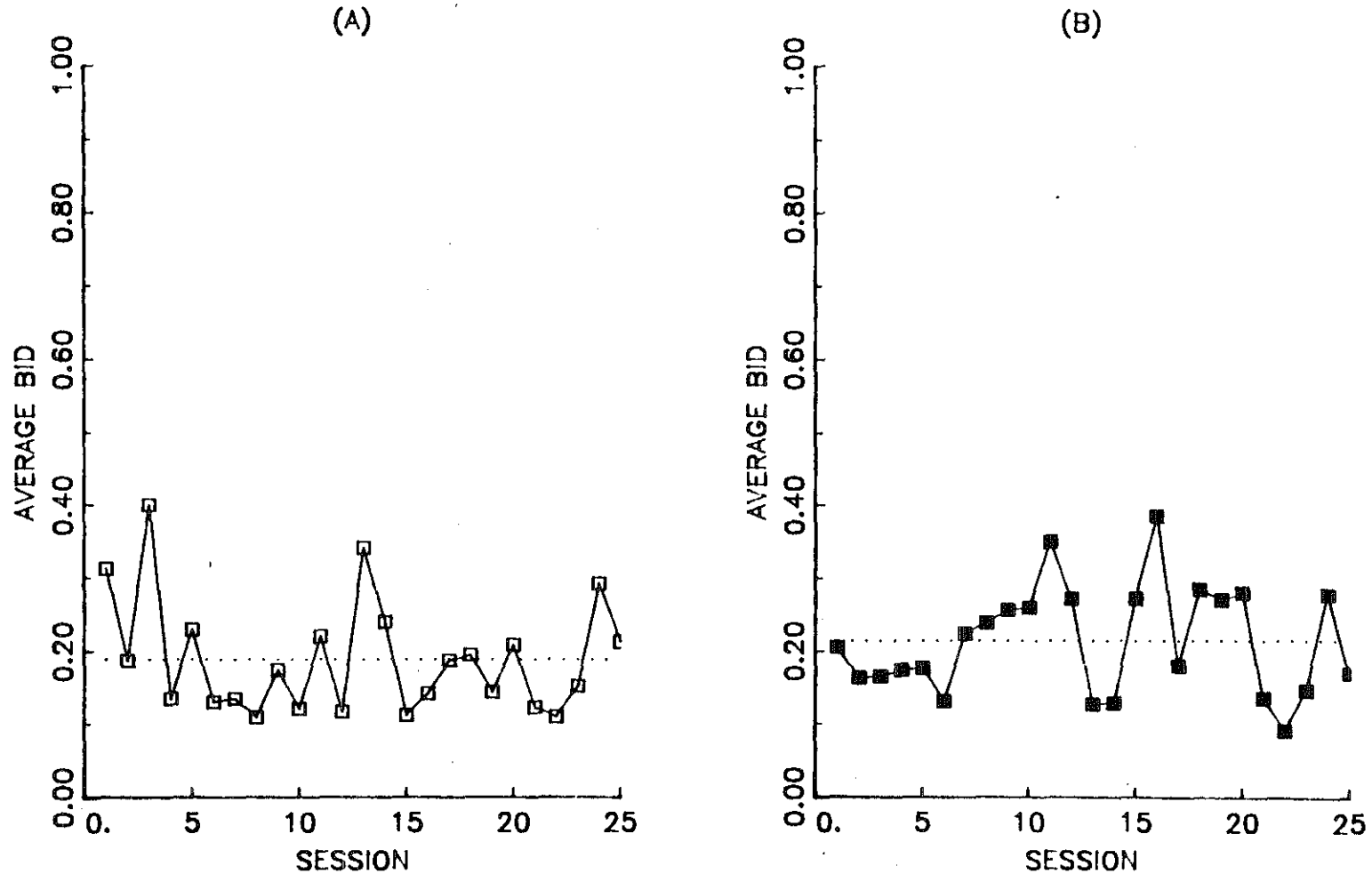


FIGURE 7.2.A : Experiment 2.A - Sole Sourcing
Average initial phase bid by
A) Sellers with commercial markets
B) Sellers without commercial markets

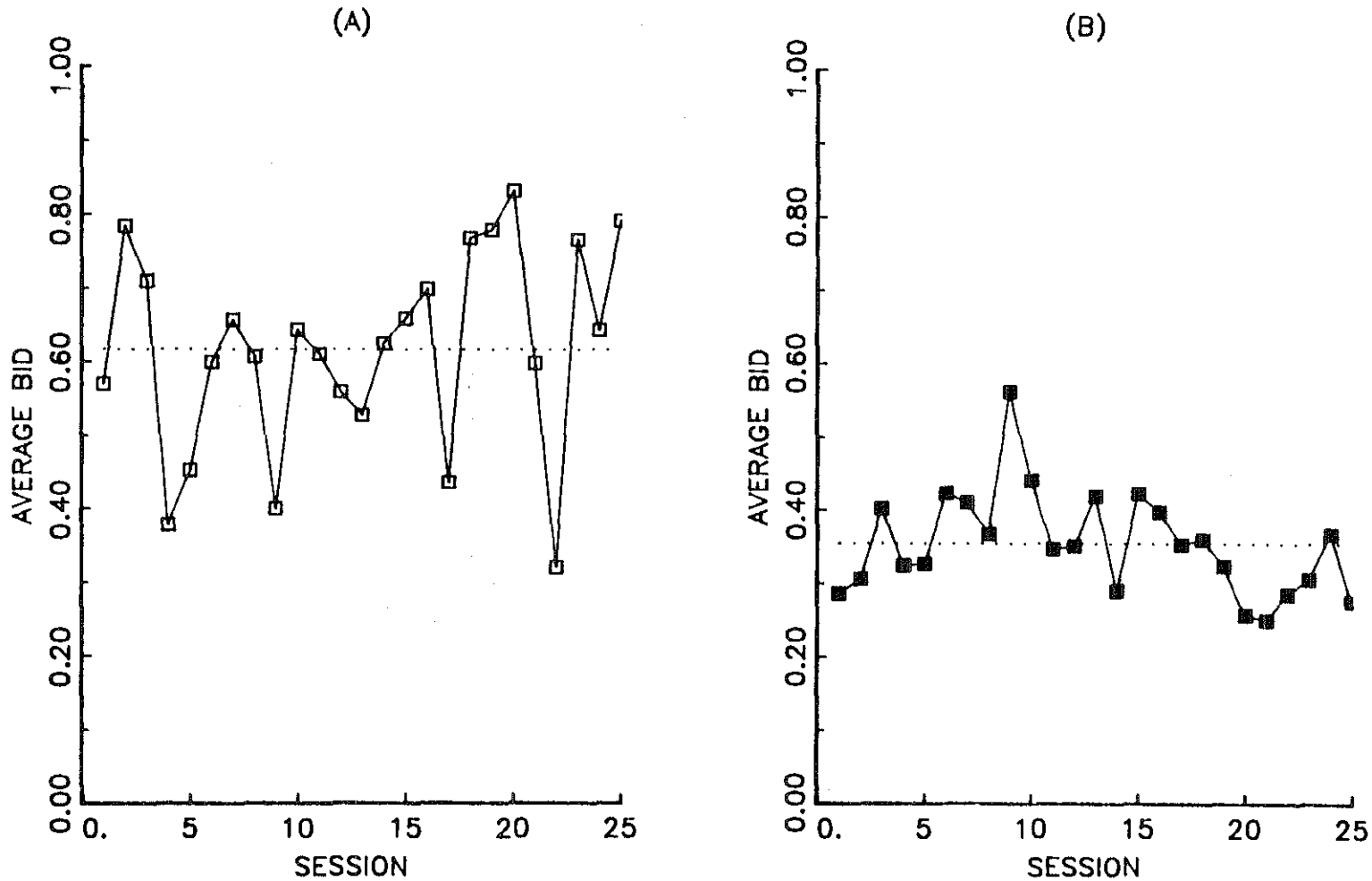


FIGURE 7.2.B : Experiment 2.B - Second Sourcing
Average initial phase bid by
A) Sellers with commercial markets
B) Sellers without commercial markets

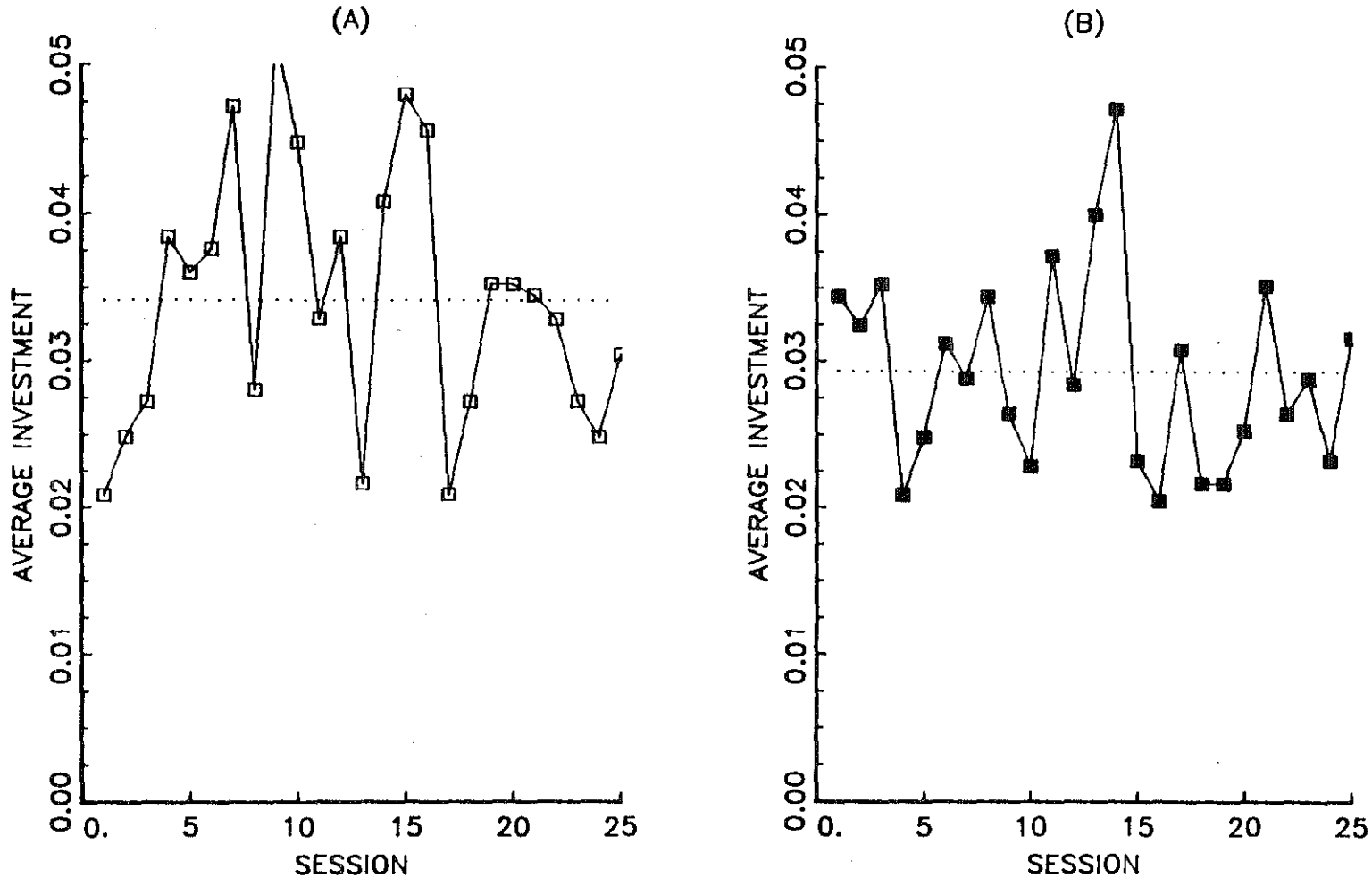


FIGURE 8.2.A : Experiment 2.A - Sole Sourcing
Average initial phase investment expenditure by
A) Sellers with commercial markets
B) Sellers without commercial markets

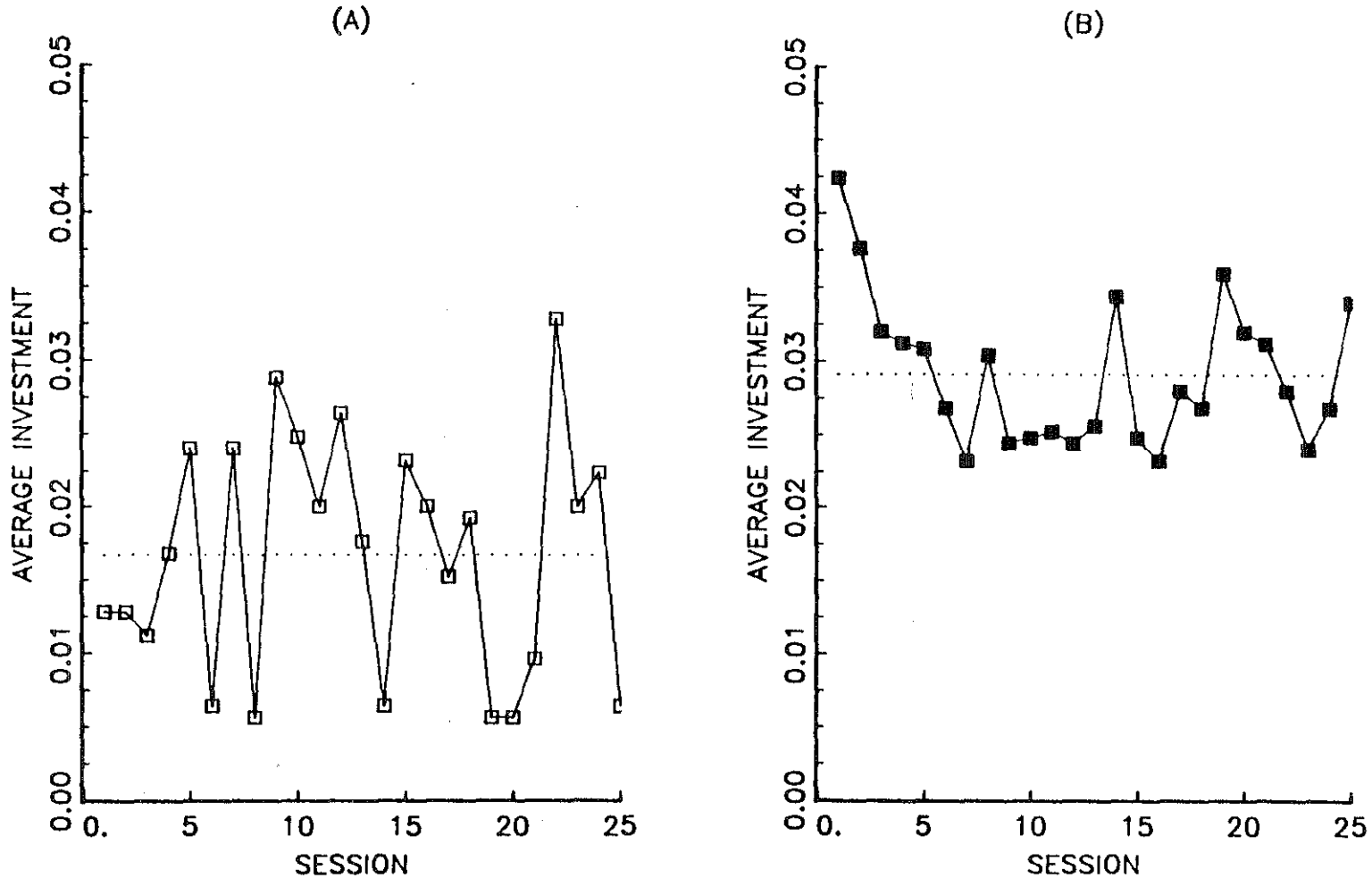


FIGURE 8.2.B : Experiment 2.B - Second Sourcing
Average initial phase investment expenditure by
A) Sellers with commercial markets
B) Sellers without commercial markets

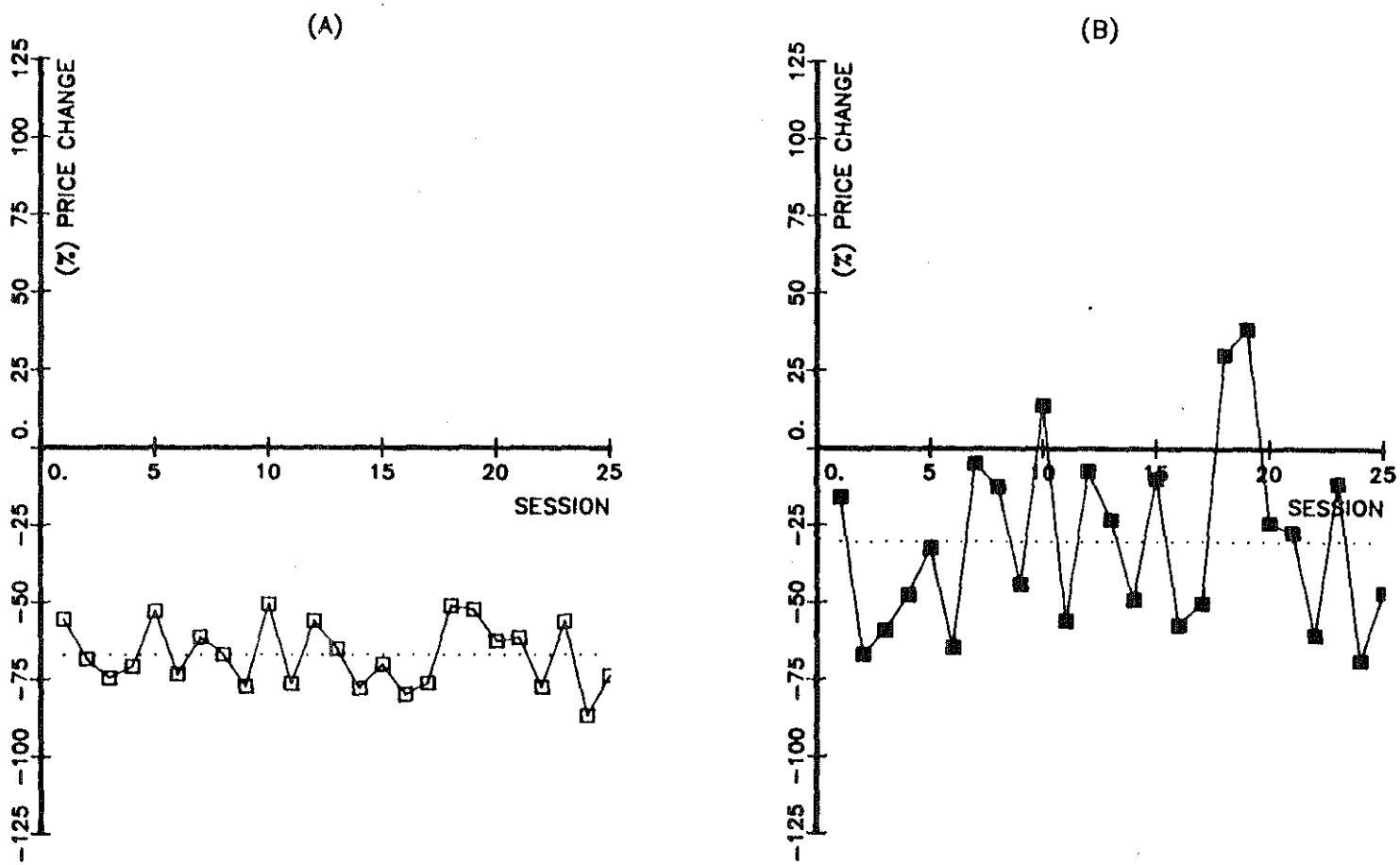


FIGURE 9.2 : Experiment 2 - Evaluation of the effect of second sourcing on reprocurement cost

A) Percentage price change due to second sourcing as measured by the procedure used in empirical studies

B) Actual percentage price change due to second sourcing

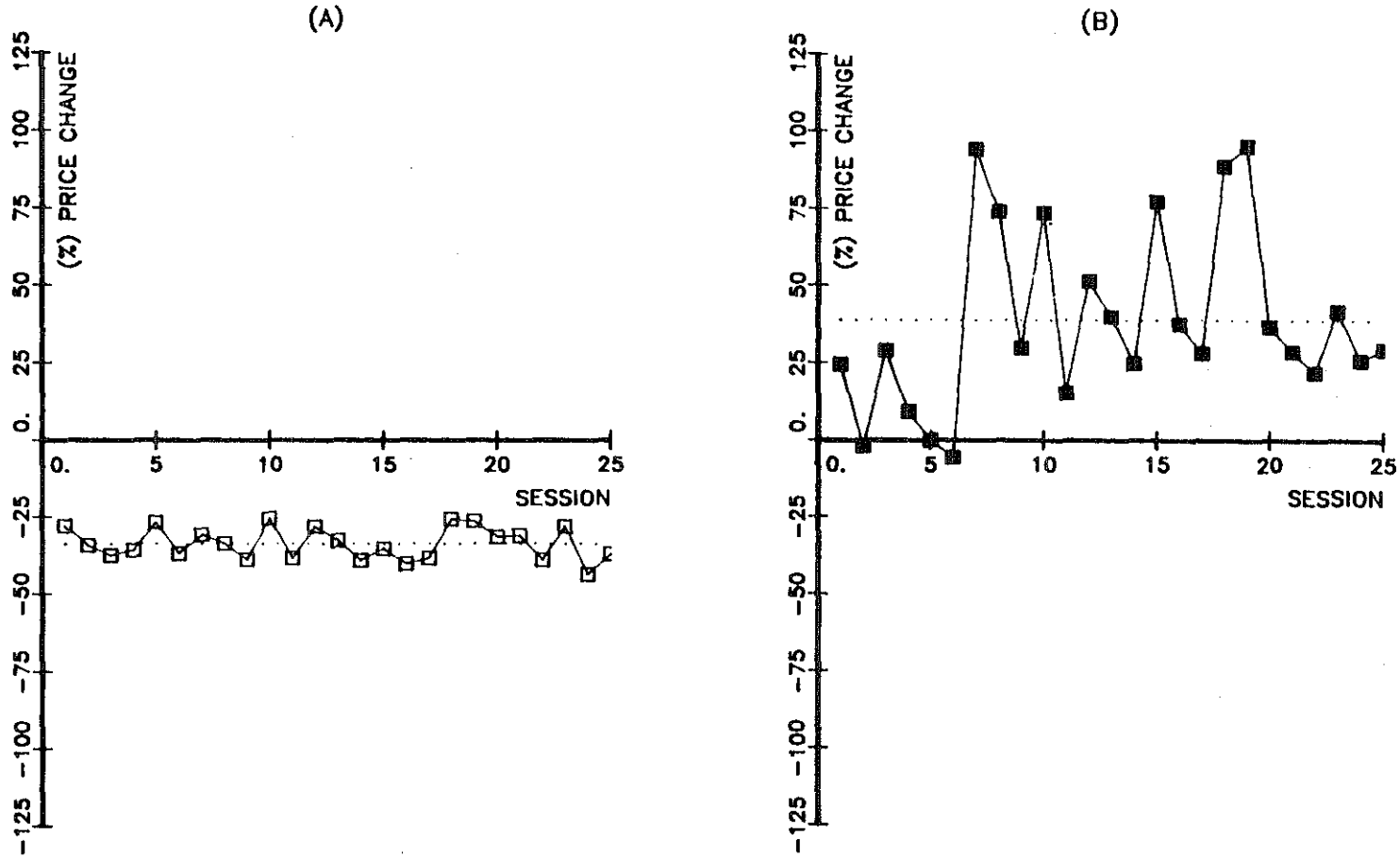


FIGURE 10.2 : Experiment 2 - Evaluation of the effect of second sourcing on total program cost
A) Percentage price change due to second sourcing as measured by the procedure used in empirical studies
B) Actual percentage price change due to second sourcing

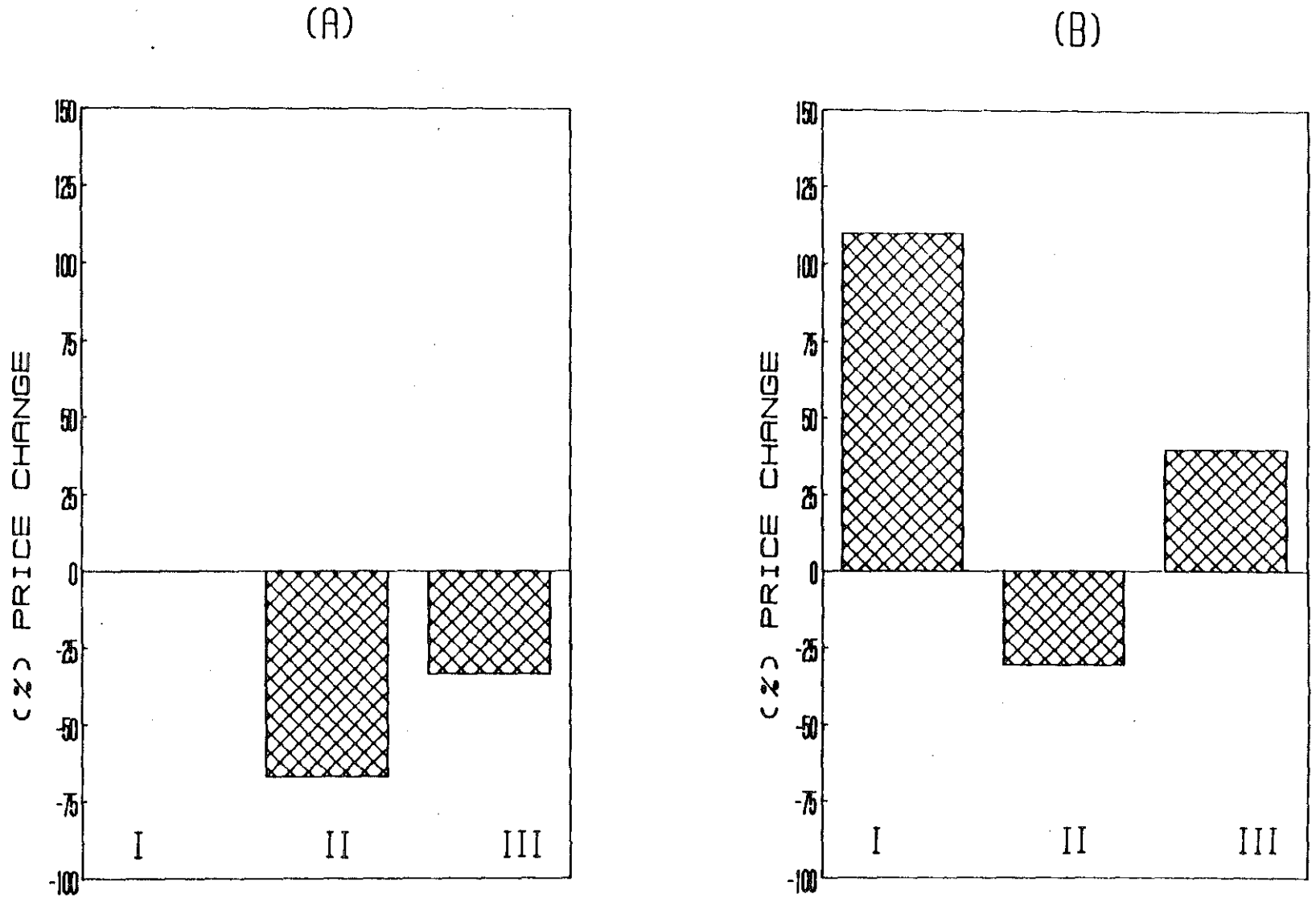


FIGURE 11.2 : Experiment 2 - Evaluation of the effect of second sourcing on I. initial procurement cost, II. reprocurement cost, III. total cost
A) Percentage price change due to second sourcing as measured by the procedure used in empirical studies
B) Actual percentage price change due to second sourcing

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