RISK AND NEED-FOR-WORK PREMIUMS IN CONTRACTOR BIDDING

By Richard de Neufville,[1] Member, ASCE, and Daniel King,[2] Student Member, ASCE

ABSTRACT: Contractors add significant premiums, on the order of 3%, to their bids when they have a low need for work or projects have high risk. An empirical study of the effect of need-for-work and project risk on contractor bid markups was conducted by assessing and analyzing utility functions obtained from construction contractors in a bid-simulation exercise. Thirty New England contractors participated in the study. The statistical analysis of utility data indicates, with a high level of confidence, that need for work and risk significantly affect contractor bid markups. A revised model of bidding is presented. The paper also discusses the implications of these need-for-work and risk premiums for owners, contractors, and the insurance industry. Specifically, project managers should seriously consider investing at least 1% of the project cost in studies that reduce the risk perceived by contractors.

INTRODUCTION

Billions of dollars' worth of construction projects are awarded annually by competitive-bidding procedures. Facility owners, developers, and contractors should thus have a deep interest in how these processes function, particularly in their inherent features that could be systematically exploited. Operations researchers should likewise be concerned with these processes: The size of these operations mean that even small improvements in efficiency would lead to significant net benefits.

In this vein, this paper documents two forms of market inefficiencies, the need-for-work and risk premiums, that systematically intrude on the bidding processes. Knowledgeable managers will be able to mitigate their effects by appropriate action. Most significantly, they have the opportunity to reduce the overall cost of a project by reallocation of its risk from the contractor to another party, either the owner or an insurance company.

This paper focuses on competitive, noncollusive bidding processes, in which contractors compete against others for the right to construct a project. It begins with a review of the models of the bidding process, focusing on their implications for managers. Based on this analysis, which identifies risk and the need for work as two salient influences on the behavior of bidders, the paper describes the research design: A two-way empirical investigation of the effect of these factors. The t-test analyses of the data demonstrate with a high level of confidence (generally over 99%) that risk and need for work each lead, independently and additively, to a premium on the total cost of a project of around 3%, which is indeed a significant transactional cost. The conclusion discusses ways managers might eliminate these inefficiencies.

[1]Chmn. of Tech. and Policy Program and Prof. of Civ. Engrg., Room E40-251, Massachusetts Inst. of Tech., Cambridge, MA 02139.

[2]Lieutenant, Civ. Engr. Corps, United States Navy, Staff Civ. Engr., NAS Barbers Point, HI 96862.

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Models of Bidding Process

The core of all the models of competitive, noncollusive bidding process for projects is based on three observations:

1. Bidding is a risky process, whose prospective benefits should be expressed in terms of expected values.
2. The expected benefits to a bidder depend jointly on the probability of winning the bid, and on the difference between this bid and the actual cost of doing the project, that is, the markup.
3. The two parameters central to the process, the probability of winning and the markup, are interdependent: The higher the markup, the lower the probability of winning.

The stereotypical model of the bidding process focuses on the optimal strategy from the bidder's perspective. It is thus that each bidder seeks to maximize the expected value of the process, EV, as a function of the profit, that is, the markup proposed, M; and the probability of winning the bid with that level of markup, $P(M)$. In equation form:

$$\text{maximize: } EV[P(M), M] \qquad (1)$$

In detail, this model takes two forms: The expected value is stated in terms either of money or of the utility for money, the way people actually feel about money (for example, that a major loss threatening the integrity of a company is far worse than a series of small losses totaling an equal dollar amount). This concept is explained in detail in numerous texts, by Raiffa (1968) and de Neufville (1990) in particular. Symbolically, the expected value is expressed either as \$ or $U(\$)$.

Expected Monetary-Value Models

The seminal competitive-bidding-strategy model was developed by Friedman (1956), and was based on maximizing the bidder's monetary value. This model was further elaborated by a series of researchers (Park 1966; Rosenshine 1972; Fuerst 1976, 1977; Ioannou 1988). Others have used it to develop computerized procedures (Morin and Clough 1969), for analyses of local construction markets (Wade and Harris 1976), and to estimate the optimum markup (Sugrue 1980).

A parallel family of models is based on the concepts set forth by Gates (1967) and subsequently elaborated by others (Baumgarten 1970; Rosenshine 1972; Dixie 1974) as well as by Gates (1976). This group of models differs from the first in that it uses a different way to calculate the probability of winning over a group of competitors [see Benjamin and Meador (1979)].

A third variant was proposed by Carr (1982, 1983). His differs from the preceding two in that it treats cost, rather than profit, as the random variable. Overall, however, all these models have the same structure and implications.

Expected Utility Models

With the propagation of the concept of utility, it became apparent that any decision model about major choices should incorporate the fact that people value money nonlinearly. This led to revisions of the basic model of bidding to include utility, as proposed by Willenbrock (1973), de Neufville et al. (1977), and Ibbs and Crandall (1982).

While a model including utility is clearly more realistic, this feature did

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not, by itself, radically change the implications for management, as discussed next. What this concept did do, however, was to underscore the fact that more factors affect bid decisions than simple estimates about the number of bidders. To comprehend the dynamics of the bidding process, it is necessary to investigate and understand the factors that influence the personal utilities of contractors.

Factors Affecting Utility

Surveys of bidders and analyses of their behavior indicate that two issues strongly influence the way contractors feel about a project and its potential profit: The risk of the project itself, and their own need for work. Ahmad and Minkarah (1988) recently documented this in their survey of 129 construction contractors. De Neufville et al. (1977) showed how this happens in the aggregate over the industry, in their statistical analysis of over 850 projects involving nearly 4,500 bids. That study used overall economic conditions as a proxy for the individual's need for work, and the size of the project as a measure of risk.

Overall, the basic model of the factors that most significantly affect the bids submitted, and thus of the bidding process, is as in Fig. 1.

Implications for Bidders

Ironically, the models of the bidding process neither have not had nor are likely to have much influence on contractors, the intended audience. This is because the only really realistic models are those that incorporate the competitors' utility for money. By knowing these utility functions, a bidder could theoretically determine the optimal markups for each competitor and use this information to win the bid. However, the requirement to know the competitors' utility for money makes the model impossible for bidders to use, since there is no conceivable way in which a contractor could hope to get its rivals to disclose their positions before the bids are due. As an alternative, these models have proposed using distributions of past bid results to determine how competitors might bid on future projects. However, this method also has its drawbacks: "it is quite unlikely that any given

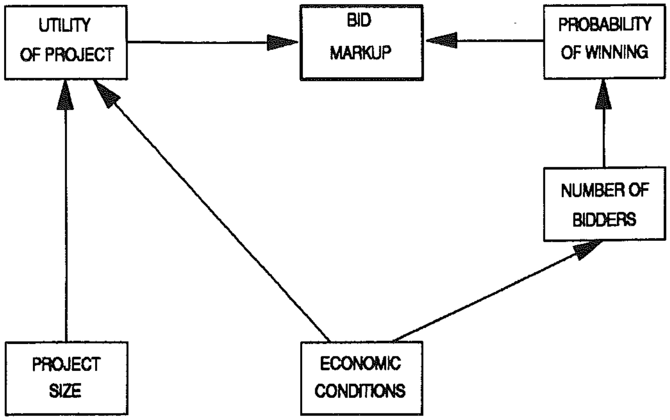

FIG. 1. Basic Expected Utility Model of Contractor Bidding at Macroeconomic Level (de Neufville et al. 1977)

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competitor could acquire sufficient data to develop the probability distributions . . . needed to use these models" (Benjamin 1972). Thus, from a bidder's point of view, these models are unworkable because the information needed to use them is difficult, if not impossible, to obtain.

Implications for Management

The models do have an important implication for management; however, they demonstrate the value of limiting the number of bidders as a means of reducing the total cost of a project from the owner's perspective. Alert managers thus now routinely limit the serious bidding to a short list of bidders.

The models have an interesting twist. As expected, they do show that the size of the winning bid decreases as the number of bidders increases. However, when the concept of utility is factored into the models, the bidders' natural risk aversion for losses mitigates the tendency toward lower bids. The model indicates that the owner as manager of the project has nothing to gain financially by having more than about six bidders (de Neufville et al. 1977).

This limit is further reinforced by the fact that it costs contractors money to prepare bids, often as much as 1% of the size of the project. To stay in business, they must recover these costs. The more bidders they face, the less likely it will be that they win any given job. To maintain workload, contractors have to bid more projects. This increased bidding drives up their overhead, and ultimately costs owners more. This phenomenon is illustrated in Fig. 2. There is thus an extra cost, a "plurality premium" associated with having too many bidders in the process. Alternatively, if contractors believe they cannot recoup these extra bid costs, because increasing their bids would make them uncompetitive, they simply will not bid the project. Thus, good contractors often avoid bidding for jobs on which there are a large number of other bidders. These inefficiencies can and should be eliminated.

The net implication for managers is that while they may want to encourage many bidders to submit a preliminary (and virtually costless) registration of

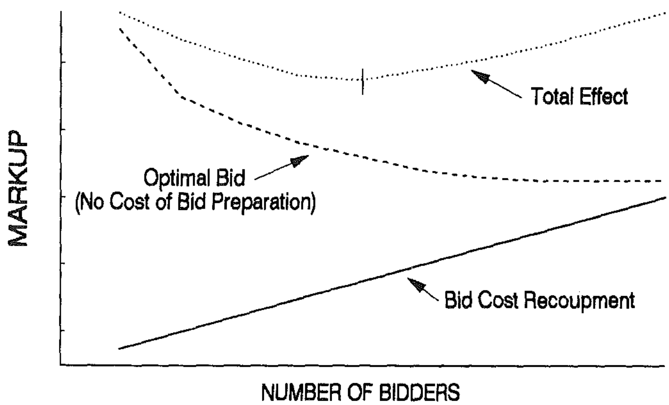

FIG. 2. Schematic Relationship between Number of Bidders and Bid Price, Indicating that Lowest Bids Are Obtained from Limited Short List [See de Neufville et al. (1977)]

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interest, they should definitely limit the process of detailed bidding to a short list of about 4–6 qualified bidders.

The questions at this point are: What other inefficiencies might be generated by the bidders' utility, by their risk aversion? What can managers do to eliminate, to mitigate these undesirable effects?

Research Design

General

To obtain a concrete understanding of the effect of risk and need for work on the behavior of bidders, it was necessary to go right to the heart of the matter, the bidders themselves. The essence of this research was thus the assessment and analysis of the utility functions of a representative sample of contractors who routinely bid for significant projects. The population surveyed covered 30 firms in the Boston area, consisting of both general contractors and mechanical and electrical subcontractors. This sample size was thought to be large enough, based on Delquie (1989), to provide significant results both overall and for subgroups. Indeed it did.

The means for assessing the utilities was an interactive computer program, ASSESS, designed and used extensively for this purpose by Delquie (1986, 1989). This software includes all the features of the best practice of psychometric measurement and experimental control. Specifically, in contrast to the more usual practice of using written questionnaires or doing a personal interview, the software both presents the person being interviewed with a standard objective presentation, and tailors its bracketing questions to the responses it receives. It is somewhat of an expert system. It has been extensively validated, in particular by Pietrzyk (1986).

The lottery-equivalent-probability method of utility assessment (McCord and de Neufville 1986; Delquie 1989; de Neufville 1990) was selected for this investigation for two reasons. One is that the lottery-equivalent scenarios are more representative of the situations actually encountered by contractors; they do not live in a world of certainty. The other is that the probability version of this method seems to generate less distortion in the assessments. In practice, there was no difficulty in executing the procedure: All respondents completed the interview and gave credible results.

Detailed Design

A standard two-way design was used, controlling for risk and need for work. Each factor was set either at a "high" or "low" level. All 30 respondents provided a utility function for each of the four conditions. The interesting feature of the approach concerns the definitions of the terms.

Project risk was defined as the downside variability of profit, and constituted information superimposed upon the other data concerning the probability of various outcomes presented in the assessment process. It can be viewed as an indication of the variance of the profit, in contrast to the mean. Low risk was given as a downside variability of 0–3%, high risk as 0–20%. Since the upper limit on profit markup in the assessment procedure was 15%, a high-risk project entailed the possibility that the bidder might lose all profit and "go into pocket." Fig. 3 shows a typical display generated by the ASSESS program in the assessment process and indicates how the project risk was presented.

The need for work was not defined precisely. It was not possible to identify a metric that would be satisfactory to the bidders.

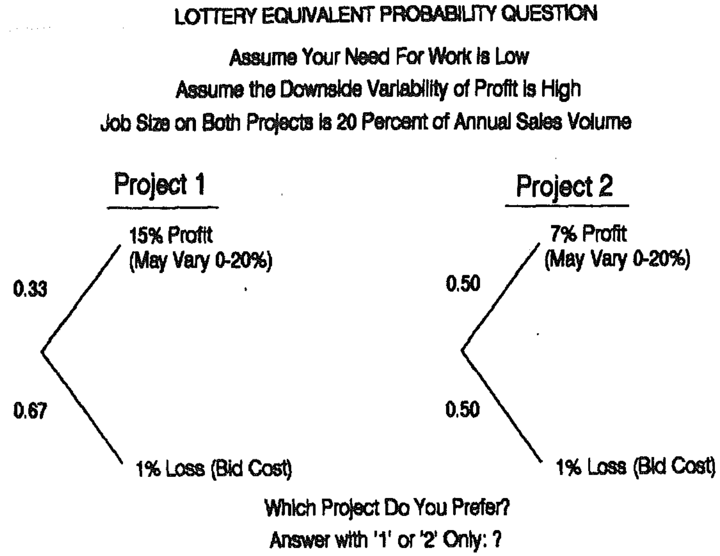

FIG. 3. Typical Display on Computer Screen Presented to Interviewee During Measurement of Utility by ASSESS Program

They all knew what it meant to need work, but could not define it precisely. Low need for work was described verbally as a situation in which "you have plenty of work and don't need the project," whereas high need for work was identified with the lack of sufficient workload to meet overhead and keep the work force employed.

The sequence of the four scenarios was varied for different contractors, to avoid *order effects*, that is, the systematic distortion of some reponses due to fatigue or whatever. Additionally, each person being interviewed had a practice session on an abbreviated questionnaire, so that they would all start their interview knowledgeably.

Qualitative Understanding of Risk and Need for Work

A qualitative interview, based on an extensive questionnaire, complemented the formal analysis. This was designed to check for significant omissions or misunderstandings of the bidding process, and to develop a deeper understanding of the factors that contribute the most to a contractor's risk or need to obtain work. Based on these interviews, the project-risk factors most frequently mentioned by the contractors were: amount of labor carried relative to project size; technical complexity of work; identity of owner/general contractor; quality of design and cooperativeness of architect/engineer; site conditions/logistics; short project schedule; and safety hazards. The need-for-work factors most frequently mentioned were current/future workload; need to meet overhead; need to employ key personnel; relationship with owner/general contractor; amount of work being bid in future; and need to employ workers.

In addition to identifying some of the critical elements that comprise project risk and need for work, the questionnaire asked the contractors how they measured or compensated for project risk or need for work in preparing

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their bids. Most contractors had no specific way of measuring or quantifying either factor. Those that did attempt to quantify risk simply compared the amount of labor they carried on a project to the total project cost. Their markup was then varied depending on the size of this ratio.

In general, the contractors appeared to have two ways for compensating for risk when developing a bid: One is to develop a standard cost estimate not considering risk, and varying the markup depending on the risk. The second method is to develop a cost estimate that adjusts productivity factors or adds contingencies based on the risk of each item being estimated, and then applying a standard markup to this risk-compensated estimate. Most contractors stated they used the latter method; a few used a combination of both. These two methods are illustrated in Fig. 4.

The most common method of quantifying or measuring a contractor's need for work was a comparison of the size of the current project backlog against the annual project workload. The lower this ratio, the greater the need for work. Additional details can be found in King (1990).

Results and Analysis

The assessment of the utility for project markups, for each of four distinct situations, proceeded smoothly. This is somewhat remarkable, in fact. Since the lottery equivalent probability methods are more complicted than the traditional certainty-equivalent approach, a number of researchers have wondered whether their use would be practical in dealing with real decision makers.

The assessment generated nine points for each utility function, being seven assessed plus the two end points. One of the advantages of the lottery equivalent method is that each point is independent, rather than tied to each of the others as in the certainty-equivalent method. This avoids chaining

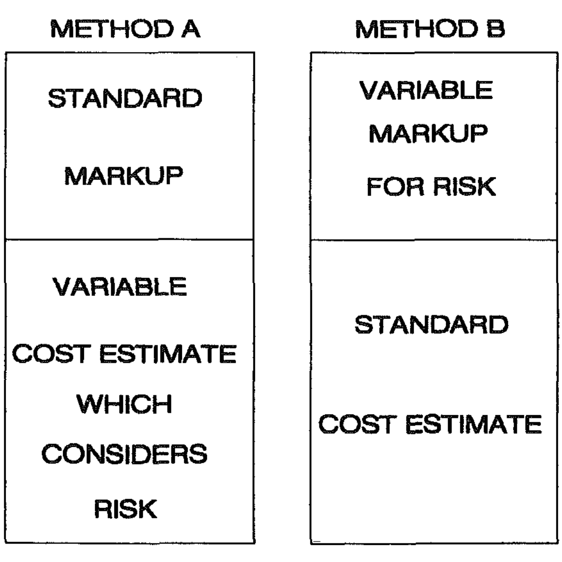

FIG. 4. Alternate Methods Used by Contractors to Compensate for Risk in Construction Bids

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and propagation of errors. Conversely, it also leads to noisy data, as in Fig. 5.

Utility functions must be fitted to these measurements. This was done with power functions of the form:

$$U(\text{markup}, \%) = A + B(\text{markup}, \%)\exp(c) \quad \ldots\ldots\ldots\ldots (2)$$

The critical parameter is the exponent, c, since the others simply tie the utility function to convenient end points defined by the analyst. To obtain the utility function for an individual in any situation, the value of the exponent was estimated for each data point, leading to an average value for the person and situation. Fig. 6 gives a typical result of this process, being the utility functions estimated for the person whose raw data is shown in Fig. 5.

Analysis

The four situations examined clearly lead to different utility functions, as Fig. 6 indicates. This effect, visually obvious from the graphs, can be documented in a number of ways. The following analyses consider the values

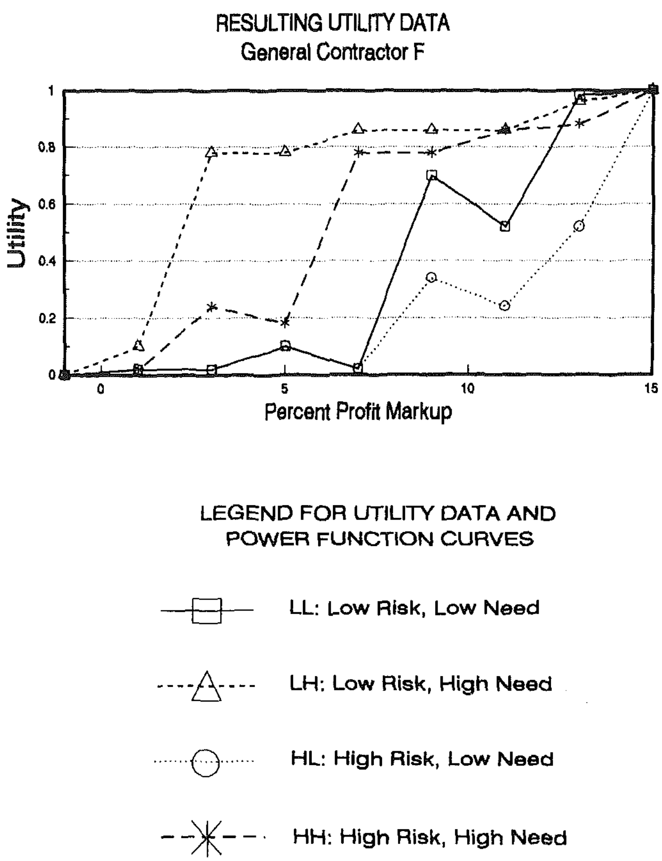

FIG. 5. Typical Raw Data on Measurement of Utility

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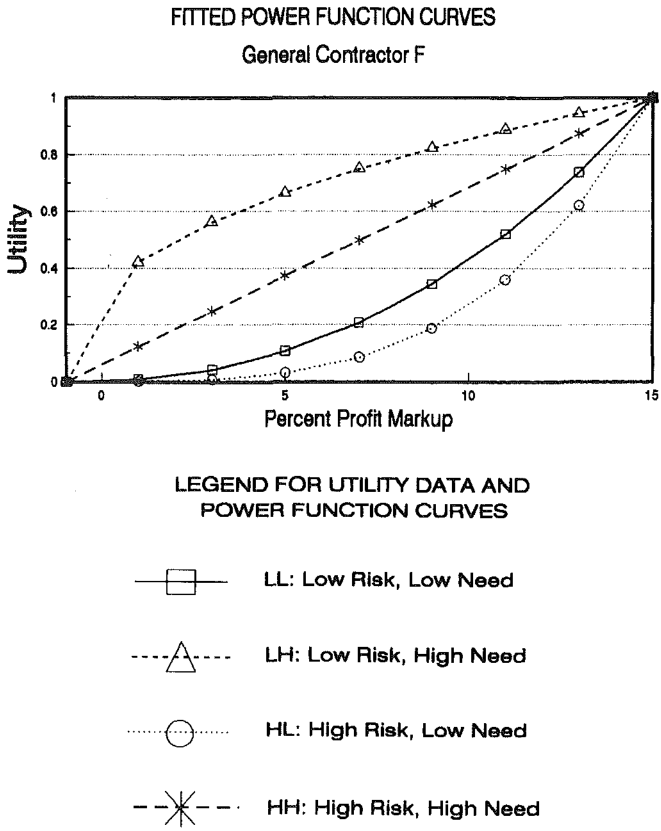

FIG. 6. Utility Power Functions Fitted to Raw Data in Fig. 5

of the markups for the value of utility of 0.5, half way between the best and the worst cases considered.

The average values, over all the contractors, are shown in Fig. 7. These are redisplayed in Fig. 8 as a difference over the base case with the lowest value, that is, the situation in which bidders have a high need for work and face a low-risk project. In that case, they are generally risk-positive, and are prepared to accept a markup less than the expected monetary value. As can be seen, there are overall surcharges as the situation either becomes more risky or the contractors have low need for work.

The distinct layering of the four situations can also be appreciated by examining the number of individuals for whom one utility curve is above, equal to, or below another. This is shown in Table 1. The pattern is striking.

Analyses for the differences in the values were done by t-tests over all contractors and for each of the subgroups. The differences between the utility functions for the four situations are significant at the 99% level overall, with less confidence for the subgroups that had only 10 individuals in the sample. Overall, the results seem conclusive.

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All Contractors

Need for Work \ Risk	Low	High
Low	10.9	12.2
High	7.0	9.3

General Contractors

Need for Work \ Risk	Low	High
Low	9.5	11.7
High	5.3	8.8

All Subcontractors

Need for Work \ Risk	Low	High
Low	11.6	12.4
High	7.9	9.6

Electrical Subcontractors

Need for Work \ Risk	Low	High
Low	11.2	12.5
High	6.9	8.0

Mechanical Subcontractors

Need for Work \ Risk	Low	High
Low	12.0	12.4
High	8.9	11.1

FIG. 7. Average Absolute Values of Contractor Markups Corresponding to Utility of 0.5 (U[0% Markup] = 0; U[15% Markup] = 1.0) for Each of Four Combinations of Low and High Risk and Need-for-Work

All Contractors

Need for Work \ Risk	Low	High
Low	3.9	5.2
High	0	2.3

General Contractors

Need for Work \ Risk	Low	High
Low	4.2	6.4
High	0	3.4

All Subcontractors

Need for Work \ Risk	Low	High
Low	3.7	4.6
High	0	1.7

Electrical Subcontractors

Need for Work \ Risk	Low	High
Low	4.3	5.6
High	0	1.1

Mechanical Subcontractors

Need for Work \ Risk	Low	High
Low	3.1	3.6
High	0	2.3

FIG. 8. Average Values of Contractor Markups Relative to Situation Giving Lowest Markups (LH = Low Risk, High Need-for-Work)

Interpretation

The experiment shows that contractors systematically add a premium to their bids to account for both the riskiness of a project and their lack of enthusiasm to do a job when they do not need the work. When either factor is present, they bid less aggressively, as their utility curves with higher *risk aversion* demonstrate.

The risk and need-for-work premiums were each on the order of 3% of the total cost of the project, as Figs. 9 and 10 indicate. Futhermore, these premiums appear additive. Naturally, the size of these premiums depends on the actual situation, and these experimental observations cannot be applied directly to any specific case. The important fact is that these premiums

TABLE 1. Number of Contractors Whose Responses are Consistent with Layering of Utility Functions Indicated by Individual Data of Figs. 5 and 6, and Average Data For Groups Given in Figures 7 and 8 (N = 30)

Comparison (1)	High risk, low need low risk, low need (2)	High risk, high need low risk, high need (3)	Low risk, low need low risk, high need (4)	High risk, low need high risk, high need (5)
(*a*) All contractors				
Number greater than	22	26	30	27
Number equal	0	0	0	0
Number less than	8	4	0	3
(*b*) General contractors				
Number greater than	8	10	10	9
Number equal	0	0	0	0
Number less than	2	0	0	1
(*c*) All subcontractors				
Number greater than	14	14	20	18
Number equal	0	0	0	0
Number less than	6	6	0	2
(*d*) Electrical subcontractors				
Number greater than	8	6	10	10
Number equal	0	0	0	0
Number less than	2	4	0	0
(*e*) Mechanical subcontractors				
Number greater than	6	10	10	8
Number equal	0	0	0	0
Number less than	4	0	0	2

represent a significant percent of the total cost of the project, comparable to the contractors' own markups above cost.

These results show how risk and need for work apply to individual bidders and firms. This microeconomic perspective complements the earlier, macroeconomic model shown in Fig. 1. The more complete model, augmented by the experimental results, appears in Fig. 11.

IMPLICATIONS FOR MANAGERS

Risk Premium

Risk costs money. Real people do not play the odds when the stakes are high; they add a cushion to their costs to protect them from disruptive losses. The experiments demonstrate that, for contractors, this premium can be as high as 3%. In fact, the risk premiums measured in this study should be viewed as minimums since they only reflect increases in profit markups to cover risk, as illustrated by method B of Fig. 4. They do not include adjustments to direct costs, such as lowered productivity factors or added contingency amounts, to cover risk, as shown in method A of Fig. 4.

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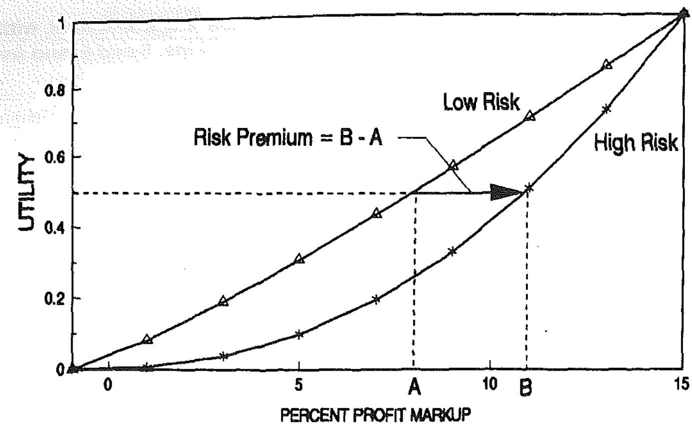

FIG. 9. Typical Risk Premium

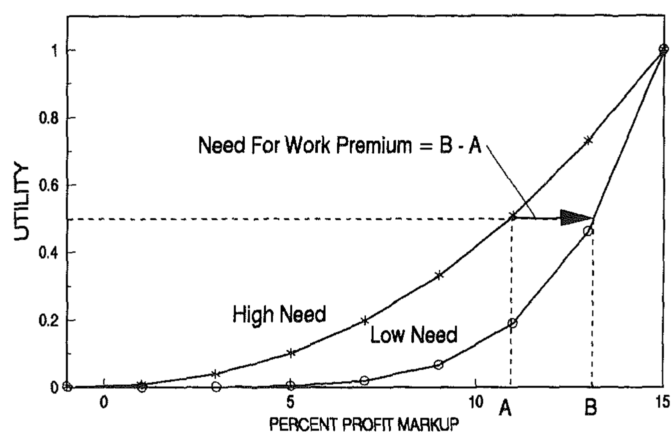

FIG. 10. Typical Need-for-Work Premium

The question is: How can managers reduce these risk premiums? One approach, of course, is to reduce the risks directly. This can be done by investing in additional preliminary work, such as site explorations, that determine the expected conditions of the project more precisely. Given that the risk premium may be about 3% of the total cost, this possibility certainly seems attractive. How this should be done depends on the specifics of the projects, and cannot be usefully discussed here.

The cost of risk can also be reduced by reallocating the risk to the parties most insensitive to it or best capable of managing it. The risk premium represents insurance against potential liabilities: Who should provide this insurance—the contractor, the owner, or some insurance company?

Owners and developers should first ask themselves to what extent they should self-insure against construction risks or share them with the contractor. Beyond intuition, the answer depends on the relative sensitivity to

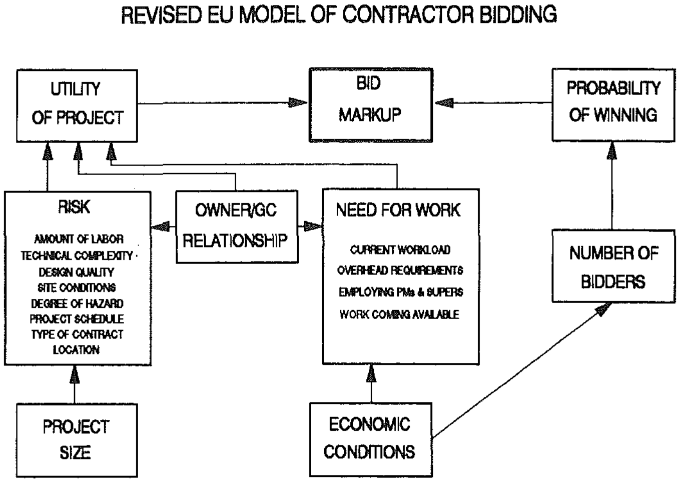

FIG. 11. New, Elaborated Expected Utility Model of Contractor Bidding

risk of the parties involved (Levitt et al. 1980; Macomber, 1989). The procedure for assessing utility used in this investigation provides a specific means for looking at this issue analytically.

The larger issue is whether either individual owners, developers, or contractors ought to be in the insurance business. They typically lack either the resources or the expertise to do this efficiently. Insurance companies would seem much better suited to carry the risk of projects.

This business would seem to have considerable potential. A risk premium of 3% provides a substantial margin to cover both the transactional costs of organizing the market and reasonable profit margins. Project owners, contractors, and insurance companies should seek to exploit this opportunity.

Need-for-Work Premium

At a macroeconomic level, it is well known that it costs more to do a job when overall economic conditions are good: Labor and supplies are tight, schedules are difficult to meet, etc. The research documents how this phenomenon applies at the microeconomic level of the firm. Whereas overall economic conditions presumably correlate reasonably well with the need for work of individual bidders, there can be numerous exceptions.

Alert owners or developers will thus want to use their knowledge of the need-for-work effect to their best advantage. This can be done in two ways: First, they should plan their work both countercyclically, to the extent possible, and in harmony with the bidders' own schedules. Secondly, they can use a contractor's desire to establish long-term relationships with owners who are steady sources of work (thus reducing the contractor's need for work in slow construction markets) as leverage to avoid need-for-work premiums in boom construction periods.

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Appendix. References

Ahmad, I., and Minkarah, I. (1988). "Questionnaire survey on bidding in construction." *J. Mgmt. in Engrg.*, ASCE, 4(3), 229–243.

Baumgarten, R. M. (1970). Discussion of " ," by John Smith. *J. Constr. Div.*, ASCE, 93(1), 88–91.

Benjamin, N. B. H. (1972). "Competitive bidding: the probability of winning." *J. Constr. Div.*, ASCE, 98(2), 313–329.

Benjamin, N. B. H., and Meador, R. C. (1979). "Comparison of Friedman and Gates competitive bidding models." *J. Constr. Div.*, ASCE, 105(1), 25–40.

Carr, R. I. (1982). "General bidding model." *J. Constr. Div.*, 108(4), 639–650.

Carr, R. I. (1983). "Impact of the number of bidders on competition." *J. Constr. Engrg. and Mgmt.*, 109(1), 61–73.

Delquie, P. (1986). "Statistical exploration of 'certainty effects' on utility assessments," thesis presented to Massachusetts Institute of Technology, at Cambridge, Mass., in partial fulfillment of the requirements of the degree of Master of Science.

Delquie, P. (1989). *Contingent weighting of the response dimension in preference matching*, thesis presented to Massachusetts Institute of Technology, at Cambridge, Mass., in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

de Neufville, R. (1990). *Applied systems analysis: engineering planning and technology management.* McGraw-Hill, New York, N. Y.

de Neufville, R., Hani, E. H., and Lesage, Y. (1977). "Bidding models: effect of bidders' risk aversion," *J. Constr. Div.*, ASCE, 103(1), 57–70.

Dixie, J. M. (1974). "Bidding models—the final resolution of a controversy." *J. Constr. Div.*, ASCE, 100(3), 265–271.

Friedman, L. (1956). "A competitive bidding strategy." *Oper. Res.*, 4, 104–112.

Fuerst, M. (1976). "Bidding models: truth and comments." *J. Constr. Div.*, ASCE, 102(1), 169–177.

Fuerst, M. (1977). "Theory for competitive bidding." *J. Constr. Div.*, ASCE, 103(1), 139–152.

Gates, M. (1967). "Bidding strategies and probabilities." *J. Constr. Div.*, ASCE, 93(1), 75–107.

Gates, M. (1976). "Gates' bidding model—a Monte Carlo experiment." *J. Constr. Div.*, ASCE, 102(4), 669–679.

Ibbs, C. W., and Crandall, K. C. (1982). "Construction risk: multiattribute approach." *J. Constr. Div.*, ASCE, 108(2), 187–200.

Ioannou, P. G. (1988). "Bidding models: symmetry and state of information." *J. Mgmt. Engrg.*, ASCE, 114(2), 214–232.

King. D. (1990). "Project cost increases due to risk and need-for-work premiums: an empirical study of bidding in the construction industry," thesis presented to the Massachusetts Institute of Technology, at Cambridge, Mass., in partial fulfillment of the requirements for the degree of Master of Science.

Levitt, R., Ashley, D. B., and Logcher, R. D. (1980). "Allocating risk and incentive in construction." *J. Constr. Div.*, ASCE, 106(3), 297–305.

Macomber, J. D. (1989). "You can manage construction risks." *Harvard Business Review*, 67(2), 155–165.

McCord, M., and de Neufville, R. (1986). "Lottery equivalents: reduction of the certainty effect in utility assessment." *Manage. Sci.*, 32(1), 56–60.

Morin, T. L., and Clough, R. H. (1969). "OPBID: competitive bidding strategy model." *J. Constr. Div.*, ASCE, 95(1), 85–106.

Park, W. R. (1966). *The strategy of contracting for profit.* Prentice-Hall, Englewood Cliffs, N. J.

Peitrzyk, V. (1985). "Effectiveness of an interactive computer program for utility assessment using certainty and lottery equivalents: an application to medical decision-making," thesis presented to the Massachusetts Institute of Technology, at Cambridge, Mass., in partial fullfillment of the requirements for the degree of Master of Science.

Raiffa, H. (1968). *Decision analysis: introductory lectures on choices under uncertainty*. Addison-Wesley, Reading, Mass.
Rosenshine, M. (1972). "Bidding models: resolution of a controversy." *J. Constr. Div.*, ASCE, 98(1), 143–148.
Sugrue, P. (1980). "An optimum bid approximation model." *J. Constr. Div.*, ASCE, 106(4), 499–505.
Wade, R. L., and Harris, R. B. (1976). "LOMARK: a bidding strategy." *J. Constr. Div.*, ASCE, 102(1), 197–211.
Willenbrock, J. (1973). "Utility function determination for bidding models." *J. Constr. Div.*, ASCE, 99(1), 133–153.