Comparative analysis of pre-bid forecasting of building prices based on Singapore data

Gunner, John; Skitmore, Martin

Published in:
Construction Management and Economics

DOI:
10.1080/014461999371240

Comparative analysis of pre-bid forecasting of building prices based on Singapore data

Dr John Gunner
Montville
Queensland
Australia

Prof Martin Skitmore
School of Construction Management and Property
Queensland University of Technology
Gardens Point
Brisbane 4001
Queensland
Australia

20 March 1998

Comparative analysis of pre-bid forecasting of building prices based on Singapore data

ABSTRACT: An analysis is described of a sample of pre-bid forecasts for 181 Singapore building contracts awarded between 1980 and 1991 in comparison with previous research results in this topic. Despite the apparent contradictions that occur between findings, it is shown that such differences could be illusionary due to a general lack of reported significance levels together with, in some cases, small sample sizes. As a result it is suggested that a general commonality in outcomes may exist in the form of a single underlying variable.

Keywords: Accuracy, building, estimating, pre-bid estimates, statistical analysis.

INTRODUCTION

Economic evaluation, monitoring and control of construction design has been practised in some form since the early 19th century (Thompson, 1968). Central to this activity is the pre-tender, or pre-bid, estimate, the earliest recorded example being Barry's excellent estimate of the London Houses of Parliament building in 1836 (Thompson, 1968). Concern has often been expressed, however, over the level of accuracy of the forecasts involved and therefore the reliability and usefulness of the practice in guiding design decisions. This has led to a series of research projects aimed at defining the levels of accuracy

achieved in construction project price forecasting and to identify and correct systematic errors as a means of improving the accuracy of such forecasts.

Skitmore (1991) and Ogunlana and Thorpe (1987) have provided summaries of many of these previous studies in terms of bias and consistency - bias being the average of differences between actual bid prices (usually lowest bid price) and forecasts, and consistency being the degree of variation around this average. Variables that have been associated with systematic changes in **bias** comprise building function (Harvey, 1979; Morrison and Stevens, 1980, 1981); type of contract (Wilson and Sharpe, 1989); conditions of contract (Skitmore, 1987; Ahuja and Campbell, 1988; Rapier, 1990); contract sum (Harvey, 1979; Flanagan, 1980; Flanagan and Norman, 1983a; Wilson *et al*, 1987b); price intensity (Skitmore *et al*, 1990); contract period (Flanagan, 1980; Morrison and Stevens, 1981; Ogunlana, 1989; Skitmore *et al*, 1990); number of bidders (Runeson and Bennett, 1983; Hanscomb Associates, 1984; Harvey, 1979; Flanagan and Norman, 1983a; Wilson *et al*, 1987a; de Neufville *et al*, 1977; McCaffer, 1976; Skitmore, 1996), good/bad years (de Neufville *et al*, 1977; Harvey, 1979; Morrison and Stevens, 1980); procurement basis (Wilson *et al*, 1987b); sector (Wilson *et al*, 1987b); number of priced items and number of drawings (Morrison and Stevens, 1980; Stevens, 1983; Diekmann, 1983); price forecaster (Flanagan, 1980; Skitmore, 1985; Skitmore *et al*, 1990). Variables associated with systematic changes in **consistency** comprise building function

(Beeston, 1974); contract work type (Skitmore, 1985; Cheong, 1991); contract sum (Morrison, 1984; Morrison and Stevens, 1980; Skitmore, 1985; Ogunlana, 1989; Thng, 1989); price intensity (Skitmore, 1985); contract period (Skitmore, 1985), good/bad years (Morrison, 1984; Ogunlana, 1989; Cheong, 1991), price forecaster (Ashworth, 1983; Ashworth and Skitmore, 1983; Jupp, 1984; Flanagan and Norman, 1983b; Skitmore, 1985; Ogunlana, 1989; Skitmore *et al*, 1990).

Despite the impressive number of these studies, seemingly little progress has been made in accounting for and reducing the errors in forecasting in any systematic way. The lack of a theory of construction price forecasting is a major contributory factor and has significantly restricted empirical progress in the topic to date (Skitmore *et al*, 1990:232). There has been some methodological progress however, which has served not only to strengthen the results of more recent research but also to increase difficulties in making comparisons between studies due to lack of consistency in approach. Early work by Jupp (1984), Morrison (1984), Morrison and Stevens (1980) for example use no statistical tests; Morrison (1984) uses 'net' rather than 'gross' forecasts; and McCaffer (1976) and Ogunlana (1989) use the mean bid instead of the contract sum as their reference point. As a result, each study has been different and produced seemingly different results. Different definitions of accuracy have been used. Beeston (1974) and Morrison (1984) use coefficients of variation alone to measure 'accuracy' but with no measures of bias, while

Skitmore *et al* (1990) use a battery of measures of both bias and consistency. Different explanatory variables have been used. Sometimes early stage forecasts (eg Skitmore, 1985, 1990) are analysed and sometimes pre-bid forecasts are analysed. Significance levels are rarely defined. Parametric methods, when used, are relatively crude with assumptions rarely checked in any other than a cursory manner.

In this paper, we describe an analysis of a new and large set of pre-bid forecast data collected in Singapore for comparison, as far as is possible, with previous research findings in this topic. The results confirm, in general terms, those of previous studies and suggest that there is a common, systematic, explanation for many of the errors that arise in pre-bid estimating.

STATISTICAL TESTS

In revisiting these previous studies, several contradictions are apparent between the results described and, in many cases, a lack of significance testing on those results. In some instances a number of researchers have commented on differences in the levels of bias and/or consistency achieved merely from observation of the results. Although such differences may be apparent in the data it does not necessarily follow that those differences are

representative of the population. They may just as easily have occurred by chance. A measure of this is provided by statistical tests of significance.

Where statistical tests have been used in previous research in this topic (*eg* Harvey, 1979; Flanagan, 1980; Flanagan and Norman, 1983a; Skitmore, 1985; Wilson and Sharpe, 1989; Ogunlana, 1989; Ogunlana and Thorpe, 1990; Skitmore *et al*, 1990; Gunner and Betts, 1990), these have been exclusively parametric tests such as regression, Pearson's correlation, Analysis of Variance, t and F tests. While parametric tests are certainly more powerful than most of the nonparametric alternatives, they do rely on certain assumption being satisfied concerning the characteristics of data being analysed. Failure to satisfy these assumptions can lead to a false rejection or acceptance, depending on the degree to which the assumptions are violated and the robustness of the particular test used.

Only a limited number of researchers have expressly stated whether their data met the relevant criteria, the expectation that price forecasting errors will be normally distributed being regarded as sufficient reason for the use of parametric methods of analysis. While there may be good theoretical reasons for this, the Central Limit Theorem often being invoked (eg. Barnes, 1971; Diekmann, 1983), they are not supported by such empirical analysis that has been done to date. Ostwald (1984), for example, found only a few variables in

cost estimating that could be approximated by normal distributions. Similarly, Bowen and Edwards (1985) have found some early stage forecasts to be closer to a uniform distribution than the expected normal distribution.

Other necessary criteria for the use of parametric statistical tests, such as the lack of multicollinearity, autocorrelation and heteroscadasticty have not been commented upon in the domain literature but are nevertheless fundamental to the choice and interpretation of an appropriately robust test. These issues will be dealt with in more detail in the analysis of a sample of Singapore data described below, and are of particular relevance in making comparisons with previous results.

THE SINGAPORE DATA

The data used for this study was collected from the Singapore office of an international firm of quantity surveyors. These comprised details of 181 contracts for a wide variety of building projects that were awarded between 1980 and the third quarter 1991, with most data being from 1987 onward. Though not a formally representative sample therefore, the sample was typical of the portfolio of an international quantity surveying practice.

Most medium and smaller projects were bid by local contractors whereas many of the larger and more complex projects had bid lists containing foreign contractors, of which Japanese companies formed the largest proportion. Further, on the larger and more prestigious projects, foreign architects were frequently employed for services ranging from concept design through to full detail design and contract administration.

Collection of data was at the pre-bid forecast stage. That is, forecasts that were prepared just prior to the issue of bid documents, or during the bidding period and using the same design information as that issued to bidders. This involved a variety of staff with differing degrees of experience. For contracts with owner provided bill of quantities the price forecasters entered rates anticipated to be used in compiling the lowest bid. For lump sum contracts (without owner provided quantities) the price forecasters prepared and priced approximate quantities.

The data are typical of any similar data that may be collected around the world. The Singapore building industry is modelled on the industry operating in the United Kingdom and other British Commonwealth countries. At the time the data were collected, the practice comprised thirty offices operating in eleven countries across four continents. With the exception of offices in North America, the procedures and practices of the organisation in relation to the preparation

of building price forecasts were quite uniform with identical price forecasting software being used in most locations. Partners and managers of the various offices were chartered quantity surveyors indicating a unifying educational experience in relation to their profession. There is no reason to doubt that the Singapore office from which this data was collected differed in any material way to the other offices in the organisation. It should also be noted that most previous pre-bid forecasting studies involved the analysis of data from a single organisation and even those that involved multiple organisations (eg Morrison, 1984) separately analysed the data from each organisation.

One relevant area where practice in Singapore differs from that of the United Kingdom and many other countries is in the aspect of 'commercial' negotiation. This derives from the Asian custom of bargaining for almost all commodities and services. In the context of the building industry it ranges from the monies paid by owners to their consultants and to contractors. This 'commercial' negotiation is not for reduced fees or bid prices due to alternative specifications but is of a purely commercial nature, being a discount (sometimes rather substantial) given on an already offered price. In the private sector the awarded contract sum is most frequently the amount submitted by a low bidder, (but not always the original lowest bidder), which has then been subject to 'commercial' negotiation for a price discount.

ANALYSIS

Following the tradition in this research topic an *ex post facto* causal comparative method (cf., Isaac and Michael, 1982) was used. This allows the investigation of possible cause-and-effect relationships by observing some existing consequences in the data and previous work and searching for plausible causal factors. For comparative purposes, and in view of unevenness of previous work, it was first necessary to identify and select the major dependent and independent variables of interest. The second issue was to identify appropriate analytical techniques to apply.

Dependent variables

The convention was followed in using the value of the awarded contract sum as the measure of the outcome of the bid process. This is line with all previous research, except Ogunlana (1989) and McCaffer (1976) who used the mean bid - an approach rejected by Beeston (1983) and Morrison (1984), as having no meaningful practical application. Also, as McCaffer's analysis has shown, the results obtained by using the mean bid are very similar to those obtained by using the lowest bid.

Based on this, four dependent variables were developed - the 'Gross Ratio', 'Net Ratio', 'Gross % Error' and 'Net % Error'. The 'Gross Ratio' variable is the pre-bid forecast divided by the awarded contract sum, while the 'Net Ratio' is the pre-bid forecast divided by the after deducting P.C., Provisional and Contingency Sums (Allowances). The 'Gross % Error' and 'Net % Error' are the same but expressed as a percentage. The 'Net Ratio' and 'Net % Error' values can be thought of as the most objective measures because they express the error in terms of the value of work actually estimated by both the contractors' estimator and the designer's forecaster. It was necessary, however, to calculate the 'Gross Ratio' and 'Gross % Error' in order to make comparisons with previous research - only Morrison (1984) having used a Net measure.

Independent variables

A variety of independent variables were used. Most of these had been used in previous work and therefore enabled good comparisons to be made. A few extra variables were available in the data. These are summarised in the results section below.

Analytical method

Parametric tests were used as a priority, due both to their superior power over nonparametric alternatives and to enable better comparison with previous work. Where the assumptions implied in the parametric tests were not satisfied, nonparametric tests were used instead. In accordance with convention, statistical significance was set at the 5% level.

The first test was to establish whether any of the subgroup means differed significantly from zero, ie., to check that the average subgroup forecasts were really biased. Where the independent variable (or its categories) exhibited a normal distribution a *t*-test (parametric) was applied to the data. Where the data had not exhibited a normal distribution a Sign test (nonparametric) was employed.

To test for bias trends, ANOVA was used for categorical independent variables and linear regression for continuous independent variables where the data sub-set exhibited a normal or log normal distribution and homogeneity of variance existed. Otherwise Kruskal-Wallis or median tests were used instead of ANOVA, and Spearman's R instead of regression.

The sample coefficient of variation was used as the measure of consistency

and Levene's test for homogeneity of variance was used to detect differences/trends in consistency, Levene's test being the most robust test available (Conover *et al*, 1981:360). As this test requires the data to be categorical, continuous independent variables were dichotomised into approximately equal sample sizes for analysis.

RESULTS

Tables 1 and 2 summarise the results of the tests for distribution, homoscedasticity, difference from zero, and analyses of bias and consistency respectively for both the Gross and Net ratios. The probability values are given as the inequalities <0.01, <0.05, <0.10, <0.15, <0.20 and n.s. These results are quite wide ranging, with Main Contract forecasts being markedly more consistent than others. They are also generally similar to other findings, with a positive bias in price forecasting being normally observed (Table 3).

The significant bivariate results are discussed in detail below, organised on the basis of Skitmore *et al*'s (1990) typology, ie. (1) the nature of the target, (2) the information used, (3) the forecasting technique used, (4) the forecaster and (5) feedback. No data on their fifth factor was available.

The Nature of the Target

Contract Work Type

Contrary to Skitmore's (1988) previous findings, for new and renovation work this variable proved to be significant in respect of bias for the Gross Ratio. The reason for a different result from Skitmore's findings may be because seven categories of work type were included in the amalgam of "Other" in this data set because of small individual sample sizes making separate analysis inappropriate. Both Gross and Net Ratio results indicate improved performance on Main Contracts. The lack of significance of the Net Ratio result, however, casts some doubt on the view that different types of work, as defined in this data set, cause different levels of bias in price forecasting.

The recorded mean coefficient of variation of 8.46% for Main Contracts is smaller than the expected 13-18% (Ashworth and Skitmore, 1983) and, being less than 10%, is classed as very low (Beeston, 1974; Ogunlana and Thorpe, 1990:221). The high mean coefficient of variation for Other Contracts may be due to the much wider variability in the nature of work comprising these contracts.

Floor Area

This variable was significant only for consistency, with consistency improving significantly with increased Floor Area. No other studies have examined the effect of Floor Area on consistency at the pre-bid stage. The range in floor areas for this data set is considerable with a minimum floor area of 66m^2 and a maximum of 371,048m^2.

Locality of Architect

Foreign architects, particularly those from Japan and the United States of America design many major projects in Singapore. Given this situation, the nationality of the architect can reflect a different quality of design and/or contract administration. This implies that either the nature of design by local and foreign architects is such that varying degrees of bias may be introduced, perhaps by specifying unusual materials or unfamiliar details that are difficult to price, and/or that contractors were making an adjustment to their bid prices to reflect their view of the likely quality of administration of the building contract by a local or foreign architect. The bias results appears to support this, although the differences are not great. The lack of any previous studies of the biasing

effect of particular designers, however, prevents any general conclusion being made.

Locality of the Contractor

The mean coefficient of variation for the foreign contractors is markedly and significantly smaller than that for local contractors. This improved performance over local competitors could be attributed to many factors. One plausible reason is that foreign contractors are normally only invited to bid for the larger contracts and, as larger contracts have smaller coefficients of variation, the effects are being confounded. Correlation (r=0.21, p=0.020) between the Locality of the Contractor and the Contract Sum offers some evidence in support of this view.

Commercially Negotiated

The normal practice in the private sector in Singapore (and many other South East Asian countries) in which the owner conducts negotiations with bidders, subsequent to the submission of their bids, in order to obtain a price discount. This procedure is not to be confused with post tender negotiations conducted

in order to investigate alternative specifications, methods or details but is a purely commercial exercise to obtain a reduction in bid prices based on the original bid documents.

The significantly smaller mean coefficients of variation for contracts subject to commercial negotiation, however, are almost certainly confounded by the 'Sector' variable, in an issue that is discussed below.

Contract Sum

Because of the wide time span of the sample, values were rebased to the third quarter 1991 by use of the local tender price index. This had the effect of reducing the sample size for analysis on account of the limited availability of tender price indices over the period.

The result supports the opinions expressed in the domain literature and corresponds with most previous findings (Flanagan and Norman, 1983a; Morrison and Stevens, 1980) in indicating that bias levels reduce with increasing contract value. The only counter examples are Harvey (1979), who found significant interaction effects with time, and Ogunlana (1989) and Skitmore and Tan (1988) who analysed only small sample sizes.

As far as consistency is concerned, several comparable studies have been reported. Ogunlana (1989:109) for instance found the mean coefficient of variation to reduce with larger contract values, while Morrison (1984) recorded the opposite trend. Cheong (1991:106) found no trend, as did Skitmore (1988) and Thng (1989), although their sample sizes were very small.

Price Intensity

No other research has examined the effect of Price Intensity on bias at the pre-bid forecast stage. Skitmore *et al* (1990:191), however, noted in their study of early stage forecasting that the "results indicate a strong negative correlation between bias and [Price Intensity]", mirroring the results found here at the pre-bid stage.

Contract Period

This variable proved significant for the Gross Ratio but not for the Net Ratio. There is a correlation in bias with the log variable against the Gross Ratio indicating a reduction in bias as the contract period is increased (*r* -0.15).

However, due to the non-significant result for the Net Ratio, the effect of the Contract Period on price forecasting performance must be considered questionable. Skitmore (1988:20) found no differences at the pre-bid stage, which casts further doubt on the significance of this independent variable.

The literature did not reveal any other work comparing the consistency of performance as affected by the contract period and so no comparisons can be made. It is interesting to note though that both bias and consistency improve in contracts of longer duration - contrary to the popular notion that forecasts containing long-range time elements are inherently less reliable.

Contract Conditions

The private sector in Singapore had, at the time of this study, only one standard form contract, issued by the Singapore Institute of Architects (SIA). These conditions depart in many respects from most standard forms used by the building industry in British Commonwealth countries. The main other form of contract used in this data set (the RHLB Form), has been employed to a much lesser degree since 1987 (when the SIA form came into common use), and is one modelled closely on the Joint Contracts Tribunal (United Kingdom) standard form 1963 edition, 1977 revision.

Significant differences in bias were found between the RHLB/SIA Forms and Other Forms but not between the RHLB Form and the SIA Form. With the knowledge that the price forecasters for this data set were not making any objective adjustment to their prices for the lesser risks under the Other Forms category it may be inferred that bidders evaluate risk in contract conditions and price their bids accordingly. No comparable variables were used in any previous studies.

Sector

The public sector contracts were the least consistently forecasted of all of the independent variables, being almost twice the coefficient of variation of the private sector contracts. The organisation that supplied the data performs price-forecasting services primarily for the private sector, which may have a bearing on the element of familiarity. Also, all the public sector work was let by open tender, in contrast with selective tendering practised by the private sector involving a smaller number of bidders. In addition, the public sector exhibits a greater range of bid prices than the private sector.

Fluctuations

The difference in consistency between contracts where fluctuations are reimbursed and those where fluctuations are not reimbursed is quite extraordinary. The reason for this could be the reduction of the bidders' risk. Also, nineteen of the twenty-four fluctuations contracts involved were for the residential buildings whose price was forecast by John. John's coefficient of variation for residential buildings was only slightly less than that for fluctuations contracts and suggests a [possible confounding effect. No comparable variable was used in any previous studies.

Market Conditions Index

The market conditions index is derived by dividing the tender price index for any given quarter by the building cost index for that quarter. The larger the index, therefore, the more buoyant is the market. Categorising the data into above and below a mid-point index was essentially the same technique as employed by de Neufville *et al* (1977), in forming their 'good years' and 'bad years'. The coefficients of variation are approximately 50% greater for 'good years' than 'bad years', suggesting that bidders not only submit lower prices during 'bad years' but that the increased aggressiveness in a bidder seeking

contracts in 'bad years' also results in reduced variability of low bids from the price forecast. Other researchers (Morrison, 1983; Ogunlana, 1989; Cheong, 1991) have analysed performance over various time frames but have not related this to any measure of the condition of the building industry at those times.

Number of Bidders

Due to the wide range involved, log values for this variable were analysed. The results indicate that Gross Ratio bias increases with an increase in the number of bidders (r=0.18) which corresponds with the findings of other research summarised in Skitmore (1996).

The Information Used

Number of Priced Items

This variable was analysed as a proxy for the amount of information used by the forecaster and the coefficient of variation was found to decrease proportionally to the number of items used. This supports the earlier

experimental findings of Jupp (1984) in pricing bills of quantities and Skitmore's (1985) in early stage forecasting. It should be noted, however, that many of the contracts with fewer priced items are demolition, groundwork or nominated sub-contracts. As mentioned earlier, the work in such contracts is likely to be more uncertain than for main contract work. Further, the variability of bid prices is much greater for those contracts with fewer priced items.

Preliminaries %

The Net Ratio coefficient of variation was found to decrease proportionally to the percentage of preliminaries content. There is no obvious explanation for this as the range of bid prices does not vary in proportion to preliminaries. The result seems to be rather tenuous though as no equivalent significant effects were found for the Gross Ratio.

Forecasting Technique

Procurement Basis

Significant forecasting bias and consistency difference were found between

bills of quantities and lump sum contracts, supporting Wilson *et al*'s (1987b) previous findings. The improved consistency in performance when pricing bills of quantities contracts appears quite remarkable, particularly when comparison is made to the general findings from the literature.

The Forecaster

Price Forecaster

No significant differences in bias were found between the three individual forecasters analysed. Significant differences in consistency, however, were found supporting Jupp (1981), Skitmore (1985) and Skitmore *et al*'s (1990) previous findings.

Number of Prior Forecasts

The results indicate that bias decreases significantly in proportion to the number of forecasts made before the pre-bid forecast. This is much as one would expect since it is likely that the greater the number of forecasts the greater the familiarity of the price forecaster with the building. No comparable variable was used in any previous studies.

CONCLUSIONS

This paper has detailed the significant results from the analyses of bias and consistency in designers' price forecasts from a sample of Singapore data in comparison with previous research in this topic. Contradictions between results and speculation as to the causes of discrepancies have been advanced wherever possible. In many cases, comparisons were restricted by the lack of identified statistically significant variables in the literature.

All significant independent variables affecting bias in price forecasting were positive. This is an interesting result because the ways in which a positive bias in forecasts may affect a project are through ill-informed decisions that are made by owners and the design team before bids are called. These carry a substantial financial impact for the owner and the design team, particularly where they are carried out based on a forecast that finally exceeds the low bid accepted by the owner. Much prior effort may eventually be seen as costly and abortive, which does not aid a project's success.

The literature review, Beeston (1987:18) for example, has commented that the level of consistency attained in practice is of some concern. It seems surprising

therefore that more attention has not been paid to consistency in price forecasting performance. Skitmore *et al* (1990:221-2) suggested that this concern "*together with the difficulties inherent in consistency analysis, should make the topic of immediate interest for practitioners and academics alike*." Practice also reveals that clients and their designers do not generally consider the consistency aspect of a designer's price forecast. It may be that the difficulties raised when considering inconsistency in building price forecasts have deterred serious consideration of the use of potential management techniques.

The need for some theory to guide research in this area has also been mentioned. The wide variety of 'connections' that have been established, or partially established, suggests that the time is now ripe for a simplifying theory to be proposed. This has not been attempted in this paper, which has been aimed at a straightforward comparison with other empirical 'results' in the topic. However, it is clear that the simple bivariate analyses used to date are but a crude means. Many of the independent variables may be intercorrelated, suggesting that all may not be as it appears. The question of confounding effects arises, where the apparent correlation of one variable, say 'size' of project, may be confounding the effect of some single underlying variable, closely related to 'size', that is really the source of the forecasting errors. To investigate this further requires a rather more sophisticated analysis than

hitherto, involving a multivariate analysis that 'partials out' such possible confounding effects. This has been attempted to a limited extent in previous work (eg., Skitmore *et al*, 1990) but never with the quality of data available in this research. An analysis of this kind has been carried out on these data, but printing limitations do not allow its description as yet. This will be described in a later paper on the subject and which will enable a basic theory to be proposed.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the time, help and guidance of Winston Hauw, Lai Meng Seng of Rider Hunt Levett and Bailey, Singapore, and Martin Betts and David Skinner of the University of Salford, UK.

REFERENCES

Ahuja, H., Campbell, W., 1988, *Estimating: from concept to completion*, Englewood Cliffs, Prentice-Hall Inc.

Ashworth, A., Cost modelling for the construction industry, *The Quantity*

Surveyor, **37**(6), Jul.

Ashworth, A., Skitmore, R.M., 1983, *Accuracy in estimating*, Occasional Paper No. 27, Englemere, Chartered Institute of Building, ISBN 0 906600 57 X.

Barnes, N.M.L., 1971, The design and use of experimental bills of quantities for civil engineering contracts, PhD thesis, University of Manchester Institute of Science and Technology.

Beeston, D.T., 1974, *One statistician's view of estimating*, *Cost Study F3*, London: Building Cost Information Service.

Beeston, D.T., 1987, A future for cost modelling, in *Building Cost Modelling and Computers,* ed. Peter Brandon London, E. & F. N. Spon Ltd.

Bowen, P.A., Edwards, P., 1985, A conceptual understanding of the paradigm shift in cost modelling techniques used in the economics of building, QS *Occasional Paper* Series, Paper No. 6 (Durban: Department of Quantity Surveying and Building Economics, University of Natal.

Cheong, P.F., 1991, Accuracy in design stage cost estimating, MSc dissertation: National University of Singapore.

Conover, W.J., Johnson, M., Johnson, M., 1981, A comparative study of tests for homogeneity of variance; with applications to the outer-continental shelf bidding data, *Technometrics*, **3**(4), Nov 360.

Neufville, De R., Hani, E.N., Lesage, Y., 1977, Bidding model: effects of bidders' risk aversion, *Journal of the Construction Division, American Society of Civil Engineers*, **103**(CO1) Mar 57-70.

Diekmann, J.E., 1983, Probabilistic estimating mathematics and applications, *ASCE Journal of the Construction Division, American Society of Civil Engineers*, **109**(3).

Flanagan, R., 1980, Tender price and time prediction for construction works, PhD thesis, University of Aston in Birmingham.

Flanagan, R., Norman, G., 1983a, The accuracy and monitoring of quantity surveyors' price forecasts in building work, *Construction Management and Economics*, **1**(2) 157-80.

Flanagan, R., Norman, G., 1983b, Risk analysis - an extension of price prediction techniques for building Work, *Construction Papers*, **1**(3).

Gunner, J., Betts, M., 1990, Price forecasting performance by design team consultants in the pacific rim, *Value in Building Economics and Construction Management CIB W-55/65 Symposium Sydney*, 3, 302-12.

Hanscomb Associates, 1984, *Area cost factors,* Report of the US Army Corps of Engineers, Hanscomb Associates Inc, 600 West Peachtree Street, NW, Suite 1400, Atlanta, Georgia 30308, USA.

Harvey, J.R., 1979, Competitive bidding on Canadian public construction contracts: stochastic analysis for optimisation, PhD thesis, School of Business Administration, University of Western Ontario.

Isaac, Michael, W., 1982, *Handbook in research and evaluation,* 2nd ed, San Diego: EdITS Publishers.

Jupp Mansfield & Partners, 1981, Reliability of detailed cost data for estimating during detailed design, (unpublished), Oct.

Lau H.M., 1991, Public sector estimating accuracy, MSc dissertation, National University of Singapore.

McCaffer, R., 1976, *Contractor's bidding behaviour and tender price prediction*, PhD thesis, Loughborough University of Technology, Sept.

Morrison, N., 1983, The cost planning and estimating techniques employed by the quantity surveying profession, PhD thesis, University of Reading.

Morrison, N., 1984, The accuracy of quantity surveyors' cost estimating, *Construction Management and Economics*, **2**(1) 57-75.

Morrison, N., Stevens, S., 1980, *Construction cost data base*, 2nd annual report of research project by Department of Construction Management, University of Reading, for Property Services Agency, Directorate of Quantity Surveying Services, DOE.

Morrison, N., Stevens, S., 1981, *Cost planning and computers* United Kingdom: Department of Construction Management, University of Reading for the Property Services Agency.

Mower-White, C.J., 1982, *Consistency in Cognitive Social Behaviour: An Introduction to Social Psychology*, London: Routedge & Kegan Paul Ltd.

Ogunlana, S., 1989, Accuracy in design cost estimating, PhD thesis,

Loughborough University of Technology.

Ogunlana, O., Thorpe, A., 1987, Design phase cost estimating: the state of the art, International Journal of Construction Management and Technology, 2(4) 34-47.

Ogunlana, S., Thorpe, A., 1990, A new direction for design phase cost estimating, *Value in Building Economics and Construction Management CIB W-55/65 Symposium Sydney 1990,* **2** 206-16.

Ostwald, 1984, *Cost estimating*, 2nd ed, Englewood Cliffs: Prentice-Hall Inc.

Rapier, 1990, How to deal with accuracy and contingency, American Association of Cost Engineers, *Transactions*, Paper K.8.

Runeson, K.G., Bennett, J., 1983, Tendering and the price level in the New Zealand building industry, *Construction Papers*, **2**(2) 29-35.

Skitmore, R.M., 1985, *The influence of professional expertise in construction price forecasts*, Salford: The University of Salford, ISBN 0 901025 09 7.

Skitmore, R.M., 1987, The effect of project information on the accuracy of

building price forecasts, in *Building Cost Modelling and Computers*, ed Peter Brandon, London, E & FN Spon Ltd, ISBN 0 419 19040 9, 327-36.

Skitmore, R.M., 1988, Factors affecting accuracy of engineers Estimates, *Cost Engineering*, **30**(10), 16-23.

Skitmore, R.M., 1991, Early stage construction price forecasting: a review of performance, The Royal Institution of Chartered Surveyors *Occasional Paper*, ISBN 0 85406 486 9.

Skitmore, R.M., 1996, The Raftery curve, *Proceedings*, Int Symp, The International Council for Building Research Studies and Documentation CIB W-55, 4-7 Sep, M Katavic (ed), Faculty of Civil Engineering, University of Zagreb, Kaciceva, Croatia, ISBN 953 96245 2 5, 241-52.

Skitmore, R.M., Patchell, B., 1990, Developments in contract price forecasting and bidding techniques, in *Quantity Surveying Techniques: New Directions*, ed P S Brandon, BSP Professional Books, 75-120, ISBN 0 632 02682 0.

Skitmore, R.M., Stradling, S.G., Tuohy, A.P., Mkwezalamba, H., 1990, *The accuracy of construction price forecasts: a study of quantity surveyors' performance in early stage estimating*, Salford: The University of Salford, ISBN 0

901025 12 7.

Stevens, S., 1983, The use of price data from analysis of bills of quantities in construction price estimating, PhD thesis, University of Reading.

Thng, 1989, Estimating accuracy at public sector - housing development board, MSc dissertation, National University of Singapore.

Thompson, F.M.L., 1968, *Chartered Surveyors: the growth of a profession*, RICS Publications.

Thorpe, A., 1985, Stability tests on a tender price prediction model, MSc thesis, Loughborough University of Technology, 1985.

Wilson, O.D., Sharpe, K., 1989, Tenders and estimates: a probabilistic model, *Construction Management and Economics*, **6**(3).

Wilson, O.D., Atkins, A.S., Sharpe, K., Kenley, R., 1987a, Competitive tendering: the ideal number of tenders, in *Proceedings*, 5th International Symposium on the Organisation and Management of Construction, London, The International Council for Building Research, Studies and Documentation, CIB W-65, the Chartered Institute of Building, Englemere, Kings Ride, Ascot, Berkshire SL5 8BJ.

Wilson, O.D., Sharpe, K., Kenley, R., 1987b, Estimates given and tenders received, *Construction Management and Economics* **5**(3).

Table 1: Gross Ratio results

	N	Ratio	CV%	LNor.	Nor.	Homo[2]	Sig0[3]	Bias	Cons
Overall	181	1.10	28.3	<0.01	<0.01		<0.01		
Building function	181	1.10				<0.10		n.s.[5]	<0.10
Commercial	82	1.08	22.6	n.s.	<0.05		<0.01		
Non-commercial	48	1.16	36.7	<0.05	<0.01		<0.05		
Residential	51	1.09	25.9	n.s.	<0.01		<0.01		
Contract work type	181	1.10				<0.01		<0.05[5]	<0.01
Main contract	86	1.03	8.5	n.s.	<0.01		<0.01		
Other contracts	95	1.17	35.5	<0.20	<0.01		<0.01		
Basement storeys	39					n.s.		<0.20[5]	n.s.
1 storey	22	1.12	26.3	<0.20	<0.05		<0.01		
2&3 storeys	17	1.03	7.8	<0.05	<0.01		<0.20[4]		
Storeys above ground	117	1.05				<0.15		n.s.[6]	<0.15
<2 storeys	44		13.0	n.s.	n.s.		<0.05[4]		
3&4 storeys	32		24.8	n.s.	<0.15		<0.10[4]		
Floor area	121	1.05				<0.05		n.s.[6]	<0.05
<7 156m^2	60		20.7	n.s.	<0.05		<0.01		
>7 156m^2	61		7.3	n.s.	n.s.		<0.01[4]		
Locality of architect	181	1.10				n.s.		<0.05[5]	n.s.
Singapore	157	1.11	25.7	<0.01	<0.01		<0.01		
Foreign	24	1.09	42.7	n.s.	<0.05		n.s.		
Locality of contractr	181	1.10				<0.05		n.s.[5]	<0.05
Singapore	138	1.12	31.1	<0.01	<0.01		<0.01		
Foreign	40	1.03	11.1	n.s.	n.s.		<0.10[4]		
Commerc. negotiated	181	1.10				<0.01		<0.20[5]	<0.01
No	54	1.19	38.8	<0.10	<0.01		<0.01		
Yes	127	1.07	20.0	<0.05	<0.01		<0.01		
Contract sum	125	1.13[1]				<0.01		<0.05[6]	<0.01
<$2 000 000	62		35.0	n.s.	<0.05		<0.01		
>$2 000 000	63		28.1	<0.15	<0.01		<0.01		
Price intensity	73	1.06[1]				n.s.		<0.01[7]	n.s.
<$1 200/m^2	35		23.3	n.s.	<0.05		<0.01		
>$1 200/m^2	38		13.6	n.s.	n.s.		<0.20[4]		
Contract period	173	1.10[1]				<0.01		<0.05[6]	<0.01

>50 weeks	86		32.3	<0.10	<0.01		<0.01		
>50 weeks	87		23.6	<0.15	<0.01		<0.01		
Contract conditions	181	1.10				n.s.		<0.05[8]	<0.15
RHLB form	76	1.11	21.8	n.s.	<0.01		<0.01		
SIA form	64	1.12	31.2	n.s.	<0.01		<0.10		
Other forms	41	1.06	34.4	<0.20	<0.01		<0.10		
Sector	181	1.10				<0.01		n.s.[5]	<0.01
Private	154	1.08	23.2	<0.01	<0.01		<0.01		
Public	27	1.21	44.3	n.s.	<0.05		n.s.		
Fluctuations	181	1.10				<0.05		<0.20[5]	<0.05
No	157	1.12	29.8	<0.01	<0.01		<0.01		
Yes	24	1.02	7.6	n.s.	n.s.		<0.20[4]		
Tender price index	125	1.13				<0.10		n.s.[6]	n.s.
>0.74%	63		24.7	n.s.	<0.05		<0.01		
<0.74%	62		38.4	<0.01	<0.01		<0.01		
Market conditions	125	1.13				<0.05		n.s.[6]	<0.05
>1.26	65		38.7	n.s.	<0.05		<0.01		
<1.26	60		24.8	<0.01	<0.01		<0.20		
Good/bad years	124					<0.05		n.s.[5]	<0.05
Bad years	65	1.14	38.7	n.s.	<0.05		<0.01		
Good years	60	1.11	24.8	<0.01	<0.01		<0.20		
Nr of bidders	179	1.10[1]				<0.20[3]		<0.05[6]	<0.15
>5 bidders	75		31.7	<0.15	<0.01		<0.20		
<5 bidders	104		26.1	<0.05	<0.01		<0.01		
Nr of drawings	177	1.10[1]				n.s.		n.s.[6]	n.s.
>40 drawings	87		24.5	n.s.	<0.05		<0.01		
<40 drawings	90		27.8	<0.10	<0.01		<0.01		
Nr of priced items	181	1.10[1]				<0.01		n.s.[6]	<0.01
>154 items	91		35.0	<0.10	<0.01		<0.05		
<154 items	90		16.2	<0.15	<0.01		<0.01		
Preliminaries %	181	1.10				<0.05		n.s.[6]	<0.20
<4.87%	90		19.6	n.s.	n.s.		<0.05[4]		
<4.87%	91		34.3	<0.05	<0.01		<0.01		
Procurement basis	181	1.10				<0.01		<0.05[8]	<0.01
Bills of quantities	87	1.08	9.1	n.s.	<0.01		<0.01		
Lump sum	94	1.12	35.9	<0.01	<0.01		<0.05		

Forecasters	63					<0.05	<0.01[4]	<0.15[5]	<0.05
Allen	15	1.09	13.4	n.s.	n.s.		<0.05[4]		
John	23	1.02	7.2	n.s.	n.s.		<0.15[4]		
Michael	25	1.06	9.2	n.s.	n.s.		<0.01[4]		
Builder experience	181	1.10				n.s.		n.s.[5]	n.s.
No	148	1.11	28.5	<0.01	<0.01		<0.01		
Yes	33	1.08	27.8	n.s.	<0.10		<0.20[4]		
Nr prior forecasts	112	1.11				n.s.		<0.05[6]	n.s.
0-1	51		29.2	<0.05	<0.01		<0.01		
2-6	61		31.7	<0.10	<0.01		<0.20		

[1]Log values
[2]Levene's test for homoscedasticity
[3]Sign test (unless otherwise stated)
[4]*t* test
[5]Kruskal-Wallis test
[6]Spearman's correlation
[7]Pearson's correlation
[8]Median test

Table 2: Net Ratio results

	N	Ratio	CV%	LNor.	Nor.	Homo[2]	Sig0[3]	Bias	Cons
Overall	181	1.12	29.6	<0.05	<0.01		<0.01		
Building function	181	1.12				<0.10		n.s.[5]	<0.10
Commercial	82	1.10	24.6	n.s.	n.s.		<0.01[4]		
Non-commercial	48	1.19	38.1	n.s.	<0.05		<0.05		
Residential	51	1.10	25.9	<0.20	<0.01		<0.01		
Contract work type	181	1.12				<0.01		<0.15[5]	<0.01
Main contract	86	1.06	12.7	<0.20	<0.01		<0.01		
Other contracts	95	1.19	36.7	<0.20	<0.01		<0.01		
Basement storeys	39					n.s.		<0.20[5]	n.s.
1 storey	22	1.16	26.6	<0.20	<0.15		<0.01[4]		
2&3 storeys	17	1.06	14.3	n.s.	n.s.		<0.20[4]		
Storeys above ground	117	1.08				<0.20		n.s.[6]	<0.20
<2 storeys	44		18.6	n.s.	n.s.		<0.05[4]		
3&4 storeys	32		26.6	n.s.	n.s.		<0.05[4]		
Floor area	121	1.08				<0.05		n.s.[6]	<0.05
<7 156m^2	60		24.2	n.s.	<0.15		<0.01[4]		
>7 156m^2	61		11.7	n.s.	n.s.		<0.01[4]		
Locality of architect	181	1.12				n.s.		<0.05[5]	n.s.
Singapore	157	1.03	26.9	<0.10	<0.01		<0.01		
Foreign	24	1.17	45.2	n.s.	<0.05		n.s.		
Locality of contractr	181	1.12				<0.05		n.s.[5]	<0.05
Singapore	138	1.15	33.3	<0.10	<0.01		<0.01		
Foreign	40	1.05	14.6	n.s.	n.s.		<0.05[4]		
Commerc. negotiated	181	1.12				<0.01		n.s.[5]	<0.01
No	54	1.21	39.3	<0.20	<0.05		<0.01		
Yes	127	1.09	26.3	n.s.	<0.10		<0.01[4]		
Contract sum	125	1.15[1]				<0.05		<0.05[6]	<0.05
<$2 000 000	62		35.8	<0.20	<0.01		<0.01		
>$2 000 000	63		30.2	n.s.	<0.01		<0.01		
Price intensity	73	1.09[1]				n.s.		<0.01[7]	n.s.
<$1 200/m^2	35		24.0	<0.20	<0.01		<0.01		
>$1 200/m^2	38		13.6	n.s.	n.s.		<0.15[4]		
Contract period	173	1.12[1]				<0.01		<0.10[6]	<0.01

>50 weeks	86		33.3	n.s.	<0.05		<0.01		
>50 weeks	87		25.6	n.s.	<0.05		<0.01		
Contract conditions	181	1.12				n.s.		<0.05[8]	n.s.
RHLB form	76	1.15	23.3	n.s.	n.s.		<0.01[4]		
SIA form	64	1.13	32.7	n.s.	<0.05		<0.10		
Other forms	41	1.07	37.6	n.s.	<0.01		<0.10		
Sector	181	1.12				<0.01		n.s.[5]	<0.01
Private	154	1.11	25.1	<0.20	<0.01		<0.01		
Public	27	1.22	45.2	n.s.	<0.10		n.s.[4]		
Fluctuations	181	1.12				<0.05		<0.10[5]	<0.05
No	157	1.14	31.0	<0.15	<0.01		<0.01		
Yes	24	1.02	8.8	n.s.	n.s.		n.s.[4]		
Tender price index	125	1.15				<0.15		n.s.[6]	<0.15
>0.74%	63		26.9	n.s.	<0.01		<0.01[4]		
<0.74%	62		39.2	<0.15	<0.01		<0.01		
Market conditions	125	1.15				<0.15		n.s.[6]	<0.15
>1.26	65		26.5	n.s.	<0.10		<0.01[4]		
<1.26	60		39.5	<0.15	<0.01		<0.20		
Good/bad years	124					<0.15		n.s.[5]	<0.15
Bad years	65	1.15	39.5	n.s.	<0.10		<0.01[4]		
Good years	60	1.14	26.9	<0.15	<0.01		<0.20		
Nr of bidders	179	1.12[1]				n.s.[3]		<0.01[6]	n.s.
>5 bidders	75		32.8	n.s.	<0.01		<0.20		
<5 bidders	104		27.7	n.s.	<0.01		<0.01		
Nr of drawings	177	1.12[1]				n.s.		n.s.[6]	n.s.
>40 drawings	87		26.3	n.s.	<0.05		<0.01		
<40 drawings	90		29.3	n.s.	<0.05		<0.01		
Nr of priced items	181	1.12[1]				<0.01		n.s.[6]	<0.01
>154 items	91		36.4	<0.15	<0.01		<0.05		
<154 items	90		18.4	n.s.	n.s.		<0.01[4]		
Preliminaries %	181	1.12				<0.05		n.s.[6]	<0.05
<4.87%	90		21.4	n.s.	<0.15		<0.05[4]		
<4.87%	91		35.6	n.s.	<0.01		<0.01		
Procurement basis	181	1.12				<0.01		<0.05[8]	<0.01
Bills of quantities	87	1.11	16.8	n.s.	n.s.		<0.01[4]		
Lump sum	94	1.14	37.4	<0.05	<0.01		<0.05		

Forecasters	63					<0.05	<0.01[4]	<0.10[5]	<0.05
Allen	15	1.15	15.9	n.s.	n.s.		<0.05[4]		
John	23	1.02	8.0	n.s.	n.s.		<0.20[4]		
Michael	25	1.08	14.6	n.s.	n.s.		<0.01[4]		
Builder experience	181	1.12				n.s.		n.s.[5]	n.s.
No	148	1.13	30.0	<0.05	<0.01		<0.01		
Yes	33	1.10	27.9	n.s.	n.s.		<0.10[4]		
Nr prior forecasts	112	1.13				n.s.		<0.10[6]	n.s.
0-1	51		30.5	<0.05	<0.01		<0.01		
2-6	61		33.0	n.s.	<0.05		<0.20		

[1]Log values
[2]Levene's test for homoscedasticity
[3]Sign test (unless otherwise stated)
[4]*t* test
[5]Kruskal-Wallis test
[6]Spearman's correlation
[7]Pearson's correlation
[8]Median test

Table 3: Comparison of bias and consistency in international performance

Source	All Contracts					Main Contracts				
	N	**Net %**	**Gross %**	**Net CV**	**Gross CV**	**N**	**Net %**	**Gross %**	**Net CV**	**Gross CV**
Cheong (1991)		n.a.	n.a.	n.a.	n.a.	88	n.a.	-0.18	n.a.	14.13
Lau (1991)	26	16.00	n.a.	25.54	n.a.		n.a.	n.a.	n.a.	n.a.
McCaffer (1976)		n.a.	n.a.	n.a.	n.a.	132	n.a.	-5.17	n.a.	16.48
Morrison (1984)		n.a.	n.a.	n.a.	n.a.		3.88	3.17	15.45	12.77
Ogunlana (1989)		n.a.	n.a.	n.a.	n.a.	61	n.a.	12.77	n.a.	11.00
Skitmore (1988)		n.a.	n.a.	n.a.	n.a.	67	n.a.	12.38	n.a.	n.a.
Skitmore (1988)		n.a.	n.a.	n.a.	n.a.	33	n.a.	-4.91	n.a.	n.a.
Thng (1989)	53	-1.20	n.a.	6.60	n.a.	31	1.10	n.a.	5.52	n.a.
Thorpe (1985)		n.a.	n.a.	n.a.	n.a.	7	n.a.	2.30	n.a.	n.a.
Thorpe (1985)		n.a.	n.a.	n.a.	n.a.	8	n.a.	6.70	n.a.	n.a.