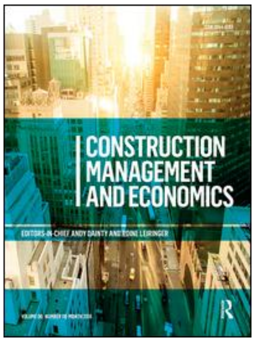

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The predictive ability of Bromilow's time–cost model

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Bromilow's log-log time–cost (BTC) model is tested and refitted with a new set of data for Australian construction projects completed between 1991 and 1998. It is shown that, as anticipated by earlier research, different parameter estimates are needed for different project types, with smaller industrial projects taking less time to complete than the smaller educational and residential projects. This results in the development of two separate models, one for industrial projects and one for non-industrial projects. No changes in parameter estimates are needed for projects with different client sectors, contractor selection methods and contractual arrangements. Alternatives to the log-log model failed to produce any improved fit. Finally, the results are compared with previous work to indicate the extent of changes in time–cost relationships in Australian construction projects over the last 40 years. This indicates a clear improvement in construction speed over the period. Furthermore, the 'public' sector group in particular has exhibited a greater variation (up to 132%) over the years.

Keywords: Cost, time, duration, time–cost, Bromilow model, linear regression, speed, productivity

Introduction

Contract time overrun is a common problem in the construction industry. Delays in building projects: increase contractors' costs (i.e. of resource replanning and construction changes, overhead costs and other time-related costs) thereby reducing the contractor's profit margin and reputation (Bromilow and Henderson, 1976); and incur clients in additional holding charges, professional fees and income lost through late occupancy. They also increase the likelihood of contractual disputes. Construction delays emanate from a diversity of origins including contractors' faults, changes in design, other unforeseen events such as inclement weather and industrial relations disputes (Kasprowicz, 1994), or just simply an overly optimistic predetermined contract duration.

The competitive nature of the industry places pressure on contractors to keep project costs as low as possible. At the same time, project durations, as determined by clients, are also kept to a minimum (Laptali *et al.*, 1996a). To avoid excessive overheads of abortive bidding, contractors are unable to spend large amounts of time or money on the estimation of project cost and duration. Many contractors simply assume that the contract duration set by the client is realistic

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and prepare their bids accordingly. It is therefore in the contractors' best interests to check if the contract periods are realistic to ensure liquidated damages will not be incurred after the original or extended contract period (Herbsman and Ellis, 1991; Wang and Huang, 1998). One approach to this is to examine the contact time performance (CTP), which is the relationship between the stipulated contract period and the time actually taken to complete the work (Walker and Sidwell, 1997). In view of the uncertainties and variabilities involved, CTP is regarded as statistical in nature (Drane, 1976).

The first empirical modelling of CTP was conducted in Australia by Bromilow (1969). The resulting model, often called Bromilow's time–cost (BTC) model, enables the construction period to be calculated according to the estimated final cost of a project. Since then, several studies have been conducted to calibrate the BTC model in Australia (Bromilow and Henderson, 1976; Bromilow *et al.*, 1980, 1988; Ireland, 1983; Mak, 1991; Sidwell, 1984; Walker, 1994, 1995), the United Kingdom (Kaka and Price, 1991), Hong Kong (Chan and Kumaraswamy, 1995; Chan, 1999) and Malaysia (Yeong, 1994). Today, the BTC model is widely recognized as the standard for estimating or benchmarking the contract period of construction projects (Ireland, 1983).

There is no guarantee, however, that the parameters of the BTC model, or even its form, will be invariant over time. A recent study by de Valence (1999) suggests that the productivity of the construction industry in Australia had a 9% increase between 1978 and 1990. Another study in Australia (Australian Bureau of Statistics, 1990) indicates that construction labour productivity grew at an annual rate of 1.9% per year between 1975 and 1990. A similar study in Hong Kong suggests that the long term productivity growth was around 2% per annum (Chau, 1993), due mainly to the improvement in production technology (Arditi and Mochtar, 2000), quality of human resources (Chau, 1998) and output of site workers (Chau and Walker, 1990). Of course, an improvement in productivity is likely to accelerate construction speed, and therefore will necessarily affect the BTC model. In addition, there is no reason to suppose that the same BTC model will be appropriate for all types of project and methods of procurement. In particular, the expectation is that different types of building might exhibit relationships of the same form, but with quite different constants (RAIA, 1989).

The aims of this paper are to revalidate the BTC model with current Australian CTP data, check on its appropriateness for various data subgroups, including those of project type, and compare with the previous models developed at different time periods.

Modelling construction time

In practice, there are two common methods of estimating project completion time: (1) according to the client's time constraints e.g. occupancy need, or (2) through a detailed analysis of work to be done and resources available, using estimates of the time requirements for each specific activity (Telford, 1994). Method (2) is known to be very tedious and often is impractical in view of the time limitations imposed on contractors at the tendering stage. Detailed estimating of construction activities also relies on the estimators' experience and judgement to interpret project and site information correctly and make the best possible decisions (Alfred, 1988). In most cases, however, time expectation is formed based on previous experience, rather than in the context of best practice (CIDA, 1993).

The BTC model (Bromilow, 1969) was developed to provide a quick and quantitative means of estimating project construction time. The model attempts to predict construction time using the estimated final cost of a construction project, expressed by

$$T = K \cdot C^{B} \quad (1)$$

Where T is the duration of construction period in working days from the date of possession of site (effectively commencement of construction) to practical completion, C is the estimated final cost of project in millions of dollars, adjusted to constant labour and material prices, K is a constant describing the general level of time performance for a \$1 million project, and B is a constant describing how the time performance was affected by project size as measured by cost.

Bromilow's (1969) study revealed that the time taken to construct a project is highly correlated with the size as measured by cost. Construction time in working days (T) could be expressed as a function of final contract sum in millions of dollars (C) based on the regression line of best fit and upper and lower quartile limits derived from the historical data on CTP.

This form of relationship between construction time and cost of building has been investigated by RAIA (1989) and been found to have continuing validity. The BTC model has also been used in recent research studies (cf. Walker and Sidwell, 1997) to improve the CTP within the construction industry.

However, one potential shortcoming of the BTC model is that it fails to consider factors other than cost when establishing the construction time (Walker, 1994). Several research studies (Ireland, 1983; Laptali *et al.*, 1996b) have been carried out to improve the accuracy of the BTC model. Ireland (1983) attempted to develop a multiple regression model based on the construction time, cost, area and number of storeys.

Progress was halted, however, by the occurrence of unreasonably high standard errors. Walker (1994) also measured the CTP, this time in terms of the gross floor area of a building. In this case, problems occurred due to the construction cost, including a significant external works component, presenting difficulties in measuring construction scope per unit of construction time.

Despite these problems, Ireland (1983, p. 137) concluded that the BTC model is 'the best predictor of construction time', the principal advantage of using construction cost per time period as a measure of project scope being that all elements of a building can be expressed in a single unit of scope measurement (Walker, 1994).

Research method

To revalidate the BTC model and examine its variability at different time periods, the actual construction time and cost of recently completed construction projects were collected and analysed. The survey population for this research was confined to projects having a contract value more than AUS$500 000 completed in the past eight years. Projects below AUS$500 000 were considered to have limited scope and complexity. A survey conducted by CIDA (1993) concluded that one major factor leading to time overrun was the prevailing economic climate. For this reason, the survey was limited to projects completed between 1991 and 1998, due to the stable economic climate in Australia at that time.

Construction companies from the two largest cities of New South Wales, Australia, i.e. Sydney and Newcastle, were considered in this study. Names and addresses of 100 construction companies were obtained by simple random selection from the telephone directories under the classification of 'building contractors'. Telephone interviews were conducted with the companies, and 44 indicated that they were interested in the study and could provide the required data.

A survey package containing a covering letter, survey instructions, six separate sets of survey questionnaires and stamped self-addressed envelopes was distributed to each company. The companies were asked to provide the details of up to six projects for analysis. Due to the sensitivity of the data required, 12 companies dropped out from the study at this stage. The 32 remaining companies provided 93 completed project surveys. This represents a reasonable response rate of 35% (based on 264 project surveys distributed).

The average time for construction was 237 working days, the longest and shortest times being 864 and 60 working days, respectively. All costs were rebased to March 1998 prices using the Building Price Index (BPI) in the price book (Rawlinsons, 1998). The average rebased cost of projects in the sample was AUS$21.4 million, the highest and lowest costs being AUS$619 million and AUS$0.50 million, respectively. The details of project surveyed are summarized in Table 1.

Analysis

Clearly the non-linear model (Equation 1) is linear in double-log form, i.e.

$$\ln(T) = \ln(K.C^B) = \ln K + B\ln C \qquad (2)$$

Letting $y = \ln T$, $x = \ln C$, $\alpha_0 = \ln K$ and $\alpha_1 = B$ gives us the standard linear regression equation

Table 1 Summary of project characteristics

Category	Classification	Number
Industry sector	Public	31
	Private	62
Project type	Residential	11
	Industrial	26
	Educational	15
	Recreational	9
	Other	32
Contract	Lump sum	61
	Design & construct	16
	Construction management	8
	Other	8
Contractor selection	Open	15
	Selective	59
	Negotiated	19
Contract duration – original (days)	⩽ 100	20
	100 – 200	34
	200 – 300	15
	300 – 400	11
	400 – 500	8
	> 500	5
Time overrun	> 20 %	33
	10 to 20 %	15
	0	33
	-10 to -20 %	5
	> -20%	7
Cost (adjust to 98 price) (AUS million)	⩽ 1	20
	1 – 10	51
	10 – 50	13
	50 – 100	5
	> 100	4
Cost overrun	> 20 %	21
	10 to 20 %	42
	0	24
	-10 to -20 %	4
	> -20%	2

$$y = \alpha_0 + \alpha_1 x \quad (3)$$

Using the number of days (T) and millions of dollars (C) spent on the project, linear model (3) may be fitted to the data, the required K and B values being $\exp(\alpha_0)$ and α_1, respectively. However, expressing the cost in units of millions of dollars was considered to be an unnecessary complication. Instead, simple dollar units (c) were substituted for C in the analysis, i.e. c = 1 000 000C.

The estimated regression coefficients are $\alpha_0 = 0.5844$ and $\alpha_1 = 0.3105$ ($r^2 = 0.588$; $F_{1,91} = 129.84$, $p<0.0000$; SE = 0.426). Only the α_1 is significant ($t_{91} = 11.39$, $p<0.000\ 000$), the constant α_0 being above the conventional 5% significance level ($t_{91} = 1.42$, $p = 0.160$). There is no evidence of undue autocorrelation (D-W $d = 1.149$) and the distribution of the residuals is not significantly different from normal (K-S $d = 0.074$, $p>0.2$). Table 2 shows the mean and variance of the residuals grouped into four log time periods. There is no significant difference between the means (ANOVA $F_{3,89} = 0.383$, $p = 0.765$), and Levine's test fails to detect significant heterogeneity ($F_{3,89} = 1.635$, $p = 0.187$).

Following previous studies, the data were then partitioned into those relating to public sector and private sector work and separate regression models fitted to each data subset. The data also allowed for partition according to the method of contractor selection (selective tendering, open tendering, negotiated price, etc.), the type of project (recreational buildings, industrial buildings, educational buildings, residential buildings, etc.) and the type of contractual arrangements (lump sum, design and construct, construction management, etc.), enabling further regression models to be fitted. The resulting regression models are summarized in Table 3. These show that, with the sole exception of the design and construct contracts, the regression constant is not significant. The α_1 values are all positive and between 0.1563 for residential projects to 0.4333 for 'other' types of contract. The standard errors (SE) of the α_1 values are, however, quite large, suggesting that these observed differences may not be significant. To test this, the residuals of the pooled data were partitioned according to these subgroups and

Table 2 Residuals against log cost (c)

		Residuals	
Log cost (c)	n	Mean	Variance
<14	26	–0.075	0.241
14–15	33	0.038	0.189
15–16	12	0.029	0.197
<16	22	0.015	0.101
Total	93	0.000	0.180

analysed for differences in means. Table 4 gives the ANOVA results together with Levine's test for heterogeneity of variances. This shows that, with the exception of the 'project type' group, there are no significant differences, in terms of means or variances. Analysing within the 'project type' group (Table 5) shows the reasons for the differences within that group. The residuals for industrial projects clearly are below the overall mean, and the residual for the residential and educational projects clearly are above the mean. Assuming that industrial projects, being generally simple in nature, are likely to be built significantly faster than other types of building, these were removed from the analysis. The resulting ANOVA on the remaining data (no industry: 'Xind') showed that the significant effects, in terms of means and variances had also been removed, as shown in the last row of Table 4.

That significant differences occur when the industrial project data are included and then disappear when the industrial project data are excluded suggests that the industrial project data may be drawn from a different population from the remainder of the data. If this is the case, then it is necessary to have two separate models, one for industrial projects (Ind) and one for non-industrial projects (Xind). The data were therefore partitioned into these two sets and a regression model fitted to each. Table 6 gives the results of the regressions and Table 7 summarizes the results of the tests of regression assumptions on each model. Table 6 shows the Xind model now to have a significant constant whereas the Ind model's constant is not significant. The Ind model also provides a much better fit with the data, with an r^2 of 0.810 against the Xind 0.538. Figure 1 shows the difference between the two models in terms of regression lines and their 95% confidence limits together with the data points. The Ind line starts much lower than the Xind line, indicating that smaller value industrial projects take less time to complete than smaller value non-industrial

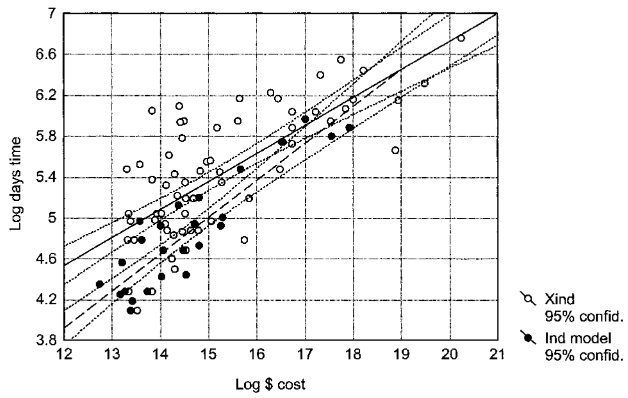


Figure 1 Xind and Ind models compared

Table 3 Regression models

		n	α_1	SE	r	r^2	r^2(adj)	α_0
All		93	0.3105	0.0273	0.767	0.588	0.583	ns
Sector	Public	31	0.3276	0.0418	0.8242	0.679	0.668	ns
	Private	62	0.3007	0.0359	0.7346	0.540	0.532	ns
Contractor selection	Selective tender	59	0.2882	0.0370	0.714	0.510	0.501	ns
	Open tender	15	0.3289	0.0482	0.884	0.782	0.765	ns
	Negotiation, etc.	19	0.3879	0.0470	0.895	0.800	0.788	ns
Project type	Recreational	9	0.2529	0.0737	0.792	0.627	0.574	ns
	Industrial	26	0.3617	0.0358	0.900	0.810	0.802	ns
	Educational	15	0.4238	0.1192	0.702	0.493	0.454	ns
	Residential	11	0.1563	0.0939	0.486	0.236	0.151	ns
	Other	32	0.3299	0.0376	0.849	0.720	0.711	ns
Contract	Lump sum	61	0.3239	0.0338	0.780	0.609	0.602	ns
	Design & construct	16	0.2108	0.0614	0.676	0.457	0.418	s
	Construction management	8	0.3607	0.0299	0.980	0.960	0.954	ns
	Other	8	0.4333	0.1398	0.785	0.616	0.561	ns

Table 4 Analysis of partitioned residuals

	ANOVA			Levine's test
Group	F	df	p	p
Sector	0.003	1,91	0.959	0.819
Project type (all)	6.059	4,88	0.000	0.042
Contractor selection	2.055	2,90	0.134	0.098
Contract	2.056	3,89	0.112	0.063
Project type (Xind)	2.014	3,63	0.121	0.226

Table 5 Residuals for project type

	Residual statistics		
Project types	n	Mean	Variance
Recreational	9	0.050	0.159
Industrial	26	-0.263	0.064
Educational	15	0.239	0.184
Residential	11	0.287	0.362
Other	32	-0.011	0.126
Total	93	0.000	0.180

projects. As the projects get larger, these differences reduce, up to a point just below log $cost = 19, where the time to complete is equal for all types of project.

The final stage of the analysis was to test for the existence of any improved forms of model. These were judged by the adjusted r^2 statistic: any model with an adjusted r^2 statistic significantly greater than Xind or Ind would be taken to be a better model. Several of the standard forms were tested separately, i.e. c, c^2, (c, $\log_{10} c$ and $1/c$ with $\ln T$ as the dependent variable. All these forms, with the addition of $\ln c$ were also entered using the forward stepwise procedure. The results (Table 8) show that no improvement could be made on $\ln c$. This process was also repeated with different forms of dependent variable, but this was abandoned as the r^2 values are not comparable between models with different dependent variables.

Comparison with previous studies

As already discussed, $B = \alpha_1$. K is obtained by setting C to 1, i.e. where c = 1 000 000. Thus, for Xind:

$$B = 0.274\,11 \text{ and } K = \exp\{1.239\,95+0.274\,11 \ln(1\,000\,000)\} = 152.463$$

and for Ind:

$$B = 0.361\,68 \text{ and } K = \exp\{-0.423\,82+0.361\,68 \ln(1\,000\,000)\} = 96.832$$

with the overall (pooled) model being:

$$B = 0.310\,50 \text{ and } K = \exp\{0.584\,41+0.310\,50 \ln(1\,000\,000)\} = 130.860$$

A comparison of these parameters with those obtained in previous analyses (Bromilow, 1969; Bromilow and Henderson, 1976; Ireland, 1983; Bromilow *et al.*, 1988) is presented in Table 9, with the effects being shown graphically in log form in Figure 2(a,b) in comparison with the Xind and Ind models and their 95% confidence limits. To provide accurate comparisons, all previous K values have been indexed to March 1998 prices according to the BPI.

Discussion of the B value

B is a constant that describes how the time performance was affected by project size as measured by cost (Bromilow, 1969; Ireland, 1983). A larger value for B

implies a longer construction time for larger projects. Walker and Sidwell (1997) found the time actually taken for the construction of all building projects generally increased with project cost, not linearly but in proportion to a power of the cost ranging from 0.25 to 0.39. These figures are consistent with the current and previous studies by researchers (see Table 9).

As illustrated in Table 9, the B values of the 'overall' category were very stable, and ranged from 0.30 (1969 and 1988 studies) to 0.31 (1998 study). The B value established in Ireland's (1983) study was 0.47, which was based on an analysis of high rise office buildings. RAIA (1989) suggested that particular types of building might exhibit relationships of the same form, but with quite different constants. This has turned out to be the case in the current study.

The B values for 'public' and 'private' groups exhibited a greater variation. In the 'public' group, the B values dropped from 0.30 (1969 survey) to 0.28 (pre-1974 projects survey) and increased to 0.38 (1988 survey), which dropped back to 0.32 in the 1998 survey. In the 'private' group, the B values decreased from 0.30 (1969 survey) to 0.28 (pre-1974 projects survey), and then increased sharply to 0.37 (post-1974 projects survey) before it returned to 0.28 (1988 survey). In the 1998 survey, the B values were found to be virtually identical for both sectors, with 0.32 and 0.30 for the 'public and 'private' sectors, respectively. A significant variation could be found between the 'public' (0.38) and 'private' (0.28) groups, especially in the 1988 survey.

Discussion of the K variable

K is a constant describing the general level of time performance for an AUS\$1 million project (Bromilow,

Table 6 Xind and Ind regression models

	n	α_0	SE	p	α_1	SE	p	r	r^2	r^2(adj)
Xind	67	1.239949	0.483	0.013	0.274111	0.032	0.000	0.733	0.538	0.530
Ind	26	−0.423819	0.524	0.426	0.361683	0.036	0.000	0.900	0.810	0.802
All	93	0.584405	0.412	0.160	0.310500	0.027	0.000	0.767	0.588	0.583

Table 7 Tests on the two models

		Model	
		Xind	Ind
D-W(d)		1.282	1.981
K-S(d)		>0.20	>0.20
ANOVA	Sector	0.674	0.137
	Project type	0.182	–
	Contractor selection	0.118	0.522
	Contract	0.194	0.085
	Log cost	0.925	0.976
Levine's test	Sector	0.149	0.086
	Project type	0.388	–
	Contractor selection	0.543	0.863
	Contract	0.264	0.083
	Log cost	0.206	0.517

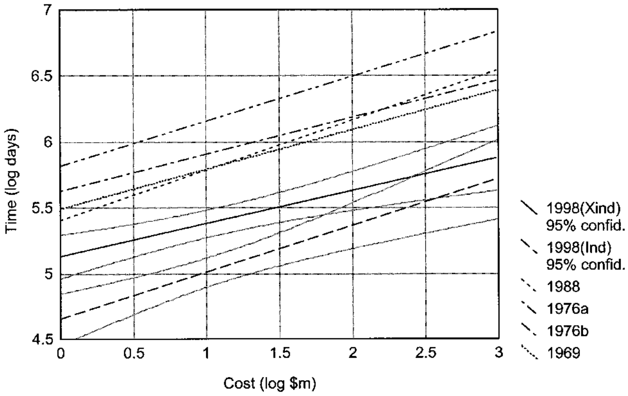
Table 8 Adjusted r^2 results for different forms

	Model		
Independent variable	All	Xind	Ind
c	0.180	0.185	0.511
c^2	0.064	0.063	0.311
$\sqrt{c}$	0.375	0.350	0.685
ln c	0.583	0.530	0.802
$\log_{10}$ c	0.583	0.530	0.802
1/c	0.473	0.438	0.521
Forward regression	0.583	0.530	0.802

Table 9 K and B values of current and previous research studies[a]

	Public		Private		Overall	
CTP Research	K	B	K	B	K	B
1998 research (Present study)	129	0.32	132	0.30	131	0.31
1988 survey (Bromilow *et al.*, 1988)	186	0.38	136	0.28	164	0.30
1983 survey (Ireland, 1983)	–	–	–	–	155	0.47
Post 1974 projects survey (Bromilow *et al.*, 1980)	286	0.34	160	0.37	–	–
Pre 1974 projects survey (Bromilow *et al.* 1980)	199	0.28	137	0.28	–	–
1969 survey (Bromilow, 1969)	211	0.30	156	0.30	177	0.30

[a] Note K values updated to March 1998 prices.



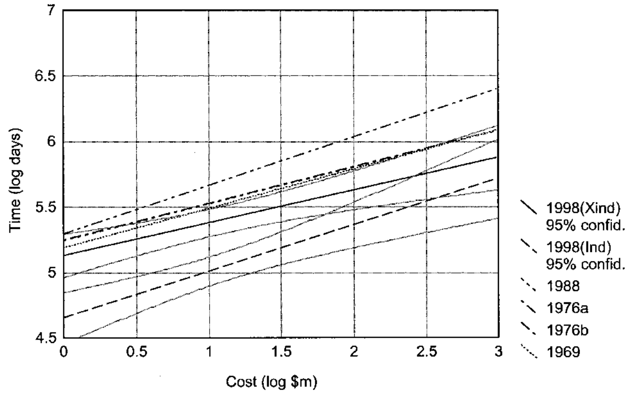


Figure 2 Results of studies (a) 'private' sector and (b) 'public' sector

1969). Inspection of Table 9 shows that the K value has changed significantly since 1969. An analysis of the 'overall' result shows that the K value was the highest in the 1969 survey (177), and gradually decreased to 131 in the 1998 study. The K value (131) for the 1998 survey reveals that the average CTP has improved by 35% (1969 survey), 18% (1983 survey) and 25% (1988 survey).

The 'private' sector indicates improvements when comparing the K values over time. Ignoring the K value for the post-1974 projects survey, the K values decreased gradually from 156 (1969 survey) to 132 (1998 survey). A comparison of the 1998 'private' group results with the previous studies suggests that improvements in CTP of 18% (1969 survey) and 3% (1988 survey) are evidenced. The high K value (160) for the post-1974 projects survey could be related to the unstable economic period between 1970 and 1976.

The K values for the 'public' sector also had a constant downward trend (when the K value for post 1974 projects survey is ignored). The 'public' sector revealed modest improvements in CTP when analysing the K value. Comparison of the 1998 public sector K value (129) with the previous studies demonstrated improvements of 64% (1969 survey) and 44% (1988 survey) in this category. A significant drop in the K value in the public sector illustrates that the CTP for public sector projects (K = 129) is becoming increasingly important, and is comparable with the CTP for private sector (K = 132).

The estimated construction duration

The aim of setting up a time–cost model is to enable clients and contractors to estimate or benchmark the construction period. To examine the variability of the BTC equations at different periods, the construction periods were calculated using the equations established in the current and previous research studies. The construction periods for contract sizes ranging from AUS$1 million to AUS$10 million were calculated based on the BTC model and the K and B values as shown in Table 9.

Figure 3 shows the construction periods calculated according to the 'overall' results in Table 9. As shown in Figure 3, the construction duration based on the 1998 survey is shorter than that of previous studies, and this is analogous to the findings of Chau (1993) and de Valence (1999). For the construction cost of AUS$1 million, the contract would take 25% (1988 survey) to 35% (1969 survey) longer to complete when compared with the 1998 survey. However, based on an AUS$10 million project, the construction periods would increase from 22% (1988 survey) to 71% (1983 survey). As shown in Figure 3, the construction period increases sharply if the K and B values from the 1983 survey are used. This is probably due to the high B value (0.47) because of the high rise office building type. This implies that the more expensive the high rise office building is, the longer the construction period will take when compared with other building types.

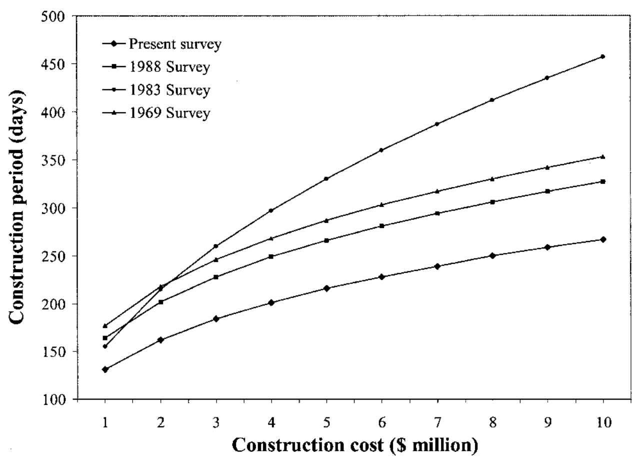


Figure 3 Estimated construction time based on 'overall' group time–cost models

The difference in construction period is less significant in the 'private' group. As shown in Figure 4, the construction periods calculated according to the 1969, pre-1974 projects and 1988 studies are fairly similar. At AUS$1 million construction cost, the difference between the 1998 study and previous research is around 5% (1988 survey) to 23% (post-1974 projects survey). When the estimate increases to AUS$10 million, the difference ranges from -7% (1988 survey) to 35% (post-1974 survey).

The 'public' sector group has the greatest variations in the estimated construction periods (see Figure 5). A difference of 44% (1988 survey) to 122% (post-1974 projects survey) is found between the 1998 and previous studies at AUS$1 million level. When the estimate increases to AUS$10 million, the difference in construction periods ranges from 40% (pre-1974 projects survey) to 132% (post-1974 projects survey). Figure 5 indicates that the 1988, pre-1974 projects and 1969 surveys are very similar. The greatest variations are between the 1998 and post-1974 projects surveys.

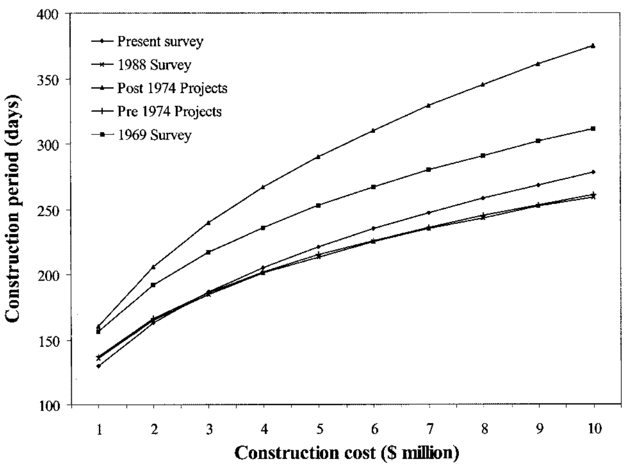


Figure 4 Estimated construction time based on 'private' group time–cost models

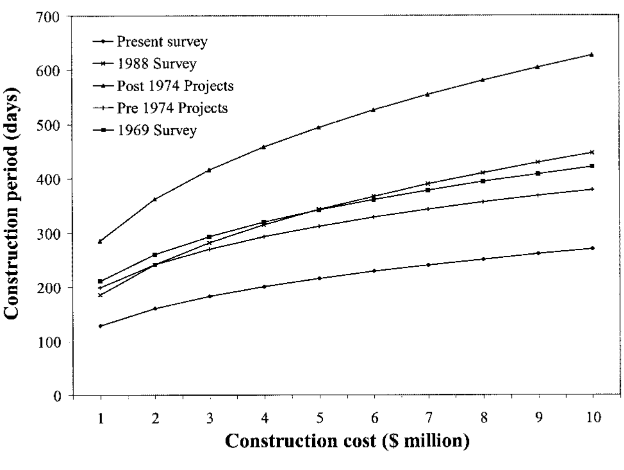


Figure 5 Estimated construction time based on 'public' group time–cost models

Conclusions

A review of the relevant literature identified the BTC model as the best measure of construction time, based on project scope.

An empirical survey of recent New South Wales construction projects was used to recalibrate the BTC model, and the results were compared with other previous studies involving projects from other States of Australia. The findings of the current study reveal that the CTP of the 'public' sector was not significantly different to that of the 'private' sector, which illustrates that the construction period of public projects in Australia is similar to that of the private projects (cf. Yeong, 1994; Chan, 1999). Also there were no significant differences found between the methods of contractor selection or contractual arrangements. Significant differences were found, however, between the project types, with smaller industrial projects taking less time to complete than the smaller educational and residential projects. This necessitated the development of two separate models, one for industrial projects (Ind) and one for non-industrial projects (Xind). Other forms of model were also tested but none found to be superior to that of the original BTC log-log model.

In comparison with previous studies, the results indicate clearly that the length of unit construction time over 1991–1998 has decreased (Figure 2). Assuming the confidence limits for the previous models to be similar to those in the current study, it is also apparent that there are distinct differences over the years. When compared with the original study conducted by Bromilow in 1969 (i.e. the 'overall' results), the K value of the 1998 study has decreased by 35%, while the B value has remained almost the same. This indicates a clear improvement in construction speed over the last three decades, which may be due to known general improvement in productivity over the period. Furthermore, the 'public' sector group in particular has exhibited a greater variation over the years, up to 132%, depending on the time period. In the face of such large changes, it is clear that regular revalidation of the models is necessary to avoid their becoming obsolescent.

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