PRODUCTION FUNCTIONS AND THE STRATEGY IMPLICATIONS FOR CRICKET IN NEW ZEALAND

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Introduction

Previous attempts to estimate production functions (defined as the systematic relationships between inputs and output) for sports have been based primarily on ice hockey, American football, basketball and baseball.[2] The relationship between output (or, in this case, team success) and the relevant performance inputs into the production process has been extended recently by J.A. Schofield to cover English cricket.[3] Following this, the authors estimated production functions for cricket in Australia and New Zealand which allow, for the first time, international comparisons inside the same sport.[4] The present study concentrates on one-day and three-day cricket in New Zealand. This will allow comparisons to be made between different forms of the same sport in terms of the relative importance of batting and bowling performance inputs and differences in strategy relative to team success. The findings, therefore, are particularly relevant to selection policy in a highly competitive professional sport where teams 'will prefer winning to losing'.[5] Indeed, if it is possible to identify the contributions of different types of batting and bowling performance to team success, this may have wider implications in terms of talent identification and coaching objectives.

This research, by following the approach in the seminal study of Australian and New Zealand cricket, is based on the only sports production function in the literature specified without *a priori* assumptions about the functional form (which is the type of mathematical/statistical relationship between inputs and output expressed in a production function). Using the production function recently introduced by Bairam[6], the authors explicitly test the functional form. This, it is argued, will reduce potential specification biases caused by *a priori* restrictions generally imposed on production functions to be estimated. It is strongly contended 'that the functional form should be determined by the data used and not the researcher'.[7]

The New Zealand Data

In New Zealand first-class cricket is played at the inter-provincial level for the Shell Trophy. Games take place over three days and allow for two innings by each team. Points are awarded for an outright win, for a first innings lead and for a first innings draw where the game might have been seriously affected by the weather. The competition itself is played in two parts: the six provinces involved play each other in a full first round and then play an abbreviated second round of repeat games against three other provinces for a total of eight games in a single season. The one-day competition, for the Shell Cup, involves the same six provinces playing each other once in a season of five games.[8] In these games, teams are limited to one innings each of 50 overs and points are awarded for a win only.[9]

Data are taken from detailed results published in the *Shell Cricket Almanack of New Zealand* covering the 1982/83 to 1987/88 seasons. The survey could have been extended into the 1970s, but it was decided to concentrate on those seasons when 'bonus' (or performance) points were not included as a measure of team success in three-day games. This avoids adding what Schofield refers to as points earned 'for occurrences other than victory'.[10] It is possible, therefore, to measure team success (or successful output) in two ways: first, as the percentage of maximum possible points (or 'points percentage') in a season and, secondly, as the percentage of games won (or ‘wins percentage’) in a season. Although Schofield uses both measures, it was decided that ‘points percentage’ was much more appropriate in the New Zealand context. The additional measure of ‘wins percentage’ is less likely to consistently reflect successful team performance the fewer the total number of games in a season.[11]

The specific contribution of both batting and bowling inputs to team success can also be measured in different ways. In the present study, batting performance is measured by runs per completed player innings and by runs scored per over. The former represents a team’s batting average or, alternatively, a team’s ability to accumulate runs relative to dismissals in an innings. The latter is a measure of the rate at which these runs are accumulated in an innings or, rather, a measure of attacking batting. Three different measures of bowling performance are introduced, namely, runs conceded per wicket taken (or a mix of attacking and defensive bowling), balls bowled per wicket (or attacking bowling) and runs scored by the opposition team per over (or defensive bowling). There are, obviously, other measures of batting and bowling performance that might have been used in the study. In fact, the plethora of statistics available in the *Cricket Almanack* and *Wisden* would have allowed, for example, runs per balls bowled, runs per hour or wickets per innings. However, the performance measures that are included capture the special features of both one-day and three-day cricket more than adequately.

The cricket purist, of course, would argue that there are other player performance variables that are directly related to team success. One of these is captaincy. Indeed, it is often suggested that a captain plays a more important strategic role in cricket than in any other sport. After all, ‘each game lasts too long, and its pace is too slow, for excitement and intuition to achieve all or most of a team’s aims’.[12] Apart from motivating players, his control of field placings and his careful manipulation of bowling changes contribute significantly to dismissals and act as a check on the opposition's run rate. Furthermore, his decision when to declare an innings closed may often be the critical difference between winning, losing and drawing a three-day game. For example, Central Districts convincingly won the Shell Trophy in the 1986/87 season with the highest percentage of maximum possible points (or 'points percentage') of any Trophy winner in the period covered in this study. Interestingly, MD Crowe, the Central Districts captain, made more declarations in this season than any provincial captain in each of the six seasons from 1982/83. More specifically, he declared 75 percent of first innings and 37.5 percent of second innings (when the average declarations for all teams over the six seasons was 31.0 percent of first innings and 25.7 percent of second innings). Unfortunately, the available data provide insufficient information with which to measure all the intangible skills of captaincy.

Again, a further dimension to team performance and success is fielding. It is an integral part of bowling performance and has a direct and vital bearing on the opposition's ability to accumulate runs. Unlike captaincy skills, fielding performance can at least be measured by recording fielding dismissals (either as catches by fielders and wicket-keepers, or as catches and run- outs) as a percentage of total dismissals. However, statistical tests showed significant collinearity (a linear mathematical relationship) between these fielding measures and each of the bowling measures. Since this leads to multicollinearity between the two inputs (where inputs are related so that it is difficult to tell which of the inputs deserve credit for explaining variations in output), the fielding measures had to be dropped from the analysis.

The pooled data used for estimation purposes are normalised. This is done by taking ratios of the variables used to their seasonal means and multiplying the ratios by 100. Therefore, for each variable used, the seasonal average is 100. Consequently, team performance in batting and bowling and team success in accumulating points (or 'points percentage') are measured relative to seasonal averages for all the teams. This procedure, as Schofield points out, 'serves to standardise data for slight variations in means as between different seasons, the result of random events such as differences in weather conditions which can influence both output and input variables'.[13]

The Model

The production functions to be estimated are variants of the general type:

$$S = f(B_i, W_j) \tag{1}$$

where S = percentage of maximum possible points

B_i = batting input i = 1,2

B_1 = runs per completed player innings (batting average)

B_2 = runs scored per over (attacking batting)

W_j = bowling input j = 1,2,3

W_1 = runs conceded per wicket taken (bowling average)

W_2 = balls bowled per wicket (attacking bowling)

W_3 = runs scored by opposition per over (defensive bowling)

It is clear that equation (1) cannot be estimated unless one makes explicit assumptions about the functional relationship between the inputs and Schofield makes *a priori* assumptions about the functional form without carrying out any statistical tests.[14] In this study, the authors explicitly test which functional form is the most appropriate and, for this purpose, use the following production function introduced by Bairam.[15]

$$(S^{\lambda} - 1)/\lambda = A + \alpha_i [(Bi^{\lambda} - 1)/\lambda] + \beta_j [(W_j^{\lambda} - 1)/\lambda] \quad (2)$$

where $\infty^{-} < \lambda < \infty^{+}$, $\alpha > 0$ and $\beta < 0$.[16]

Bairam has shown that, as long as λ- + ≤ 1, equation (2) satisfies all the requirements of a neo-clssical production function. In this model, the elasticity of technical substitution between batsmen and bowlers is defined by:

$$\sigma = 1/(1-\lambda) \quad (3)$$

It is clear from (3) that:

$\sigma \geq 0$ as $\lambda \leq 1$

and

$\sigma < 0$ as $\lambda > 1$

Consequently, as long as the functional form is restricted to values of lambda no greater than unity (that is, as long as the functional form satisfies the properties of a neo-classical production function), equation (2) is a CES production function. Therefore, it is obvious that in this model σ depends upon the value of lambda obtained from the data used for estimation purposes.[17]

The Results

For one-day and three-day cricket in New Zealand, equation (2) is estimated using the specified batting and bowling input measures and the appropriate maximum likelihood procedure in SHAZAM computer package.[18] The results obtained are presented in Tables 1 and 2. It can be seen from the tables that all the estimated coefficients have the correct signs (i.e. $\alpha_i > 0$, $\beta_j 0$, i = 1,2 and j = 1,2,3). Furthermore, with the exception of two α_2 coefficients in Table 1, they are statistically significant at the 0.95 confidence level.

Turning to the lambda values obtained, regardless of the input measures used, the estimated equations reported in Tables 1 and 2 suggest the functional form can be approximated by a linear model.[19] This implies that substituting a batsman with a bowler, or a bowler with a batsman, *is technically* very easy in both one- day and three-day cricket.

These results raise a number of interesting issues in relation to strategy and team selection for both forms of cricket in New Zealand. For one-day cricket, the best strategy (that which maximises the probability of winning) is the combination of attacking batting and defensive bowling given in equation (6) in Table 1. This is similar to Schofield's findings for the John Player League and confirms the conventional wisdom surrounding the one-day limited overs game. Clearly, when the length of a team's innings is based on a prescribed maximum number of overs, the rate at which runs are scored (attacking batting) is more important than the ability to 'occupy the crease'. Furthermore, where success depends simply on scoring more runs than the opposition, irrespective of wickets lost by either team, restricting the opposition's run rate (defensive bowling) is more important than taking wickets (attacking bowling).[20] The results do show that the second-best strategy for one-day cricket is batting average (or a team's ability to accumulate runs relative to dismissals) and defensive bowling given in equation (3) in Table 1. However, adding together the absolute values of the coefficients in equations (6) and (3) in the Table, it can be seen that the probability of winning markedly declines by nearly 24 percent by shifting from the best to the second-best strategy. Moreover, choosing any of the other strategy options would reduce the probability of winning still further by 40 percent or more.

TABLE 1
THE CES PRODUCTION FUNCTION ESTIMATES:
ONE-DAY SHELL CUP CRICKET, 1982/83-1987/88

	A	Batting Coefficients:		Bowling Coefficients:					
	A	α1	α2	β1	β2	β3	λ	R^2	σ
(1)	108.54	1.12		- 1.27			0.98	0.543	50.00
	(2.40)	(3.44)		(-4.26)					
(2)	97.65	1.20			-1.31		0.96	0.466	25.00
	(1.93)*	(3.40)			(-3.24)				
(3)	111.54	1.36				-1.48	1.00	0.385	∞
	(1.46)*	(3.72)				(-2.21)			
(4)	121.71		1.07	-1.44			0.97	0.430	33.33
	(1.84)*		(1.73)*	(-4.63)					
(5)	124.49		0.98		- 1.49		0.95	0.320	20.00
	(1.65)*		(1.42)*		(-3.25)				
(6)	127.20)		1.62			-1.89	1.00	0.349	∞
	(1.31)*		(2.32)			(2.55)			

Data Source: See text

Notes: Figures in parentheses are t-values; * indicates a coefficient not significantly different from zero at the 0.95 confidence level.

TABLE 2
THE CES PRODUCTION FUNCTION ESTIMATES:
THREE-DAY SHELL TROPHY CRICKET, 1982/83-1987/88

		Batting Coefficients:		Bowling Coefficients:					
	A	α_1	α_2	β_1	β_2	β_3	λ	R^2	σ
(1)	78.52	0.81		-1.40			0.91	0.514	11.11
	(3.51)	(2.96)		(-4.56)					
(2)	24.49	0.90			-1.61		0.92	0.426	12.50
	(2.99)	(3.10)			(-3.55)				
(3)	135.72	0.95				-0.84	1.03	0.368	∞
	(2.01)	(3.51)				(-2.91)			
(4)	42.36		1.68	-1.41			0.96	0.467	25.00
	(0.83)*		(2.28)	(-4.42)					
(5)	46.73		2.13		-1.70		0.96	0.402	25.00
	(0.61)*		(2.80)		(-3.70)				
(6)	-3.09		1.68			-0.69	1.03	0.251	∞
	(-0.02)*		(2.00)			(-2.12)			

Data Source: See text.

Notes: Figures in parentheses are t-values; * indicates a coefficient not significantly different from zero at the 0.95 confidence level.

Although the best strategy for both the Shell Cup and the John Player League is clearly attacking batting and defensive bowling, inside this strategy-mix bowling is undoubtedly the more important of the two performance measures. In New Zealand, defensive bowling is nearly 17 percent more important than attacking batting and, furthermore, bowling measures are consistently and significantly more important than batting measures whatever the strategy-mix. A number of reasons might be suggested for this. First, the special rules applied to one-day cricket (for example, the tighter control on field placings, the stricter definition of ‘no balls’ and ‘wides’ and the restriction on the number of overs allowed to each bowler) make it that much more difficult for bowlers to adjust to this form of cricket than is the case for batsmen. Indeed, one might argue that the very essence of the limited over game is the exciting ‘chase for runs’ and to guarantee this the game is deliberately tilted in favour of batsmen rather than bowlers. Secondly, teams can expect one or more of their batsmen to succeed; if one fails, others are capable of making a positive contribution to the team total. For bowlers, on the other hand, the mandatory 50 overs must be completed and it is difficult or, sometimes, impossible to avoid using a bowler whose performance on the day is below average.[21] Thirdly, a batting side can pace itself over 50 overs and a flagging run-rate can be improved in a few overs. A bowler, however, is limited to 10 overs, often on good wickets with field placings not of his choosing, and he cannot afford the luxury of a few bad overs. The pressure on a bowler to perform at a high pitch throughout his bowling stint (and still contribute to fielding) is considerable.

The estimated equations reported in Table 1 suggest that the functional form can be approximated by a linear model. Therefore, substituting a batsman with a bowler (or vice versa) is technically very easy. The weight of evidence, however, would seem to indicate that selection *at the margin* should always lean towards a bowler and not a batsman for one-day cricket. If, as is commonly the case, the *marginal* selection is to be an all-rounder, the results point towards picking a bowler who can bat a bit rather than a batsman who can bowl on occasions. This is an interesting finding because it appears to run counter to accepted selection policy for one-day games in New Zealand.[22] Detailed information on Shell Cup games shows that although teams usually include four specialist bowlers, the rest of the bowling is often carried by batsmen who occasionally bowl. Selection policy that instinctively leans more towards batting than bowling might suggest that selectors have been very slow to respond to strategic differences in approach imposed by the one-day game.[23]

For three-day Shell Trophy cricket, however, the best strategy-mix is the combination of attacking batting and attacking bowling given in equation (5) in Table 2. This is similar to Schofield's findings for the English County Championship and his arguments that 'the rate of scoring may be a more powerful influence on success than the ability to occupy the crease' and that 'attacking bowling] skills are more important than defensive skills' can be applied equally to three-day cricket in New Zealand.[28] There is support for the view that occupying the crease to amass large batting totals is not essential if the opposition is dismissed cheaply and when captains adopt a positive approach to declarations. In this latter situation, the slow accumulation of runs in the first innings might delay a declaration to the point where stalemate is inevitable. In the second innings, the timing of a declaration depends so much on a run rate which achieves that subtle balance between what is perceived as a realistic target of runs required by the opposition to win, the time available for them to achieve that target and the time needed to dismiss the opposition. Furthermore, at some point in a three-day game (unlike a one-day game) the opposition's batsmen simply have to be dismissed in order to achieve a successful outcome. More importantly, if there are no declarations, the opposition's batsmen have to be dismissed twice in order to win a three-day game. Defensive bowling as a strategy option, therefore, is quite inappropriate. The second-best strategy for three-day cricket, given in equation (4) in Table 2, is the combination of attacking batting and bowling average (which is a measure of attacking and defensive bowling). However, shifting from the best to the second-best strategy again reduces the probability of winning by 24 percent. Other strategy options would reduce the probability of winning still further by 53 percent or more.

Inside the best strategy-mix for three-day cricket, attacking batting is a little over 25 percent more important than attacking bowling. This, to some, extent, may reflect the quality of New Zealand wickets, which generally favour bowlers.[25] It can also be argued that attacking batting provides that tactical platform from which teams can declare and then control and dictate the eventual outcome of a game. Batting is really the critical element in three-day cricket; more often than not, bowling is just a vital support component in the strategy-mix. The information presented in Table 3 would seem to confirm this. In the 1986/87 season, Central Districts convincingly won the Shell Trophy with an inferior bowling performance to Otago, the second-placed team, but with a vastly superior batting performance. Similarly, Otago won the Shell Trophy in 1985/86 with a weaker bowling performance than in the 1986/87 season but with a much better batting performance. Therefore, given that the elasticity of substitution is also relatively high for three-day cricket, the evidence suggests that *at the margin* selection should certainly favour a batsman. If the *marginal* selection is an all-rounder, he should be a batsman who can bowl and not a bowler who can bat.

TABLE 3

A COMPARISON OF BATTING AND BOWLING MEASURES: CENTRAL DISTRICTS AND OTAGO

Province/ Season	Batting				Bowling		Percentage of Maximum Possible Points
	Runs per 100 balls	Runs per completed innings	Runs per over	Runs per hour	Wickets per balls bowled	Runs conceded per wicket taken	
Central Districts 1986/87	53.1	41.4	3.2	53.5	1:55.5	30.6	59.4
Otago 1986/87	48.7	24.3	2.9.	45.4	1:54.9	24.7	48.4
Otago 1985/86	52.6	34.1	3.2.	52.5	1:65.7	28.2	54.7

Data Source: See text.

Conclusion

The estimated production functions for one-day and three-day cricket reveal important differences in strategy and consequent team selection in relation to successful performance (or output). Given the relevant performance inputs, the strategy which maximises the probability of winning is attacking batting and defensive bowling in the Shell Cup and attacking batting and attacking bowling in the Shell Trophy. Inside the ideal strategy-mix, bowling is relatively more important in the one-day game and batting relatively more important in the three-day game. Since substituting a batsman with a bowler, or a bowler with a batsman, is technically very easy in both games, when the choice rests between a batsman or a bowler, selection *at the margin* should be a bowler in one-day cricket and a batsman in three-day cricket. For both games, everything else being equal, the evidence suggests that selection should favour forceful rather than timid batsmen. In terms of bowling, however, strategy dictates that the combination of bowlers for the three-day games need not be appropriate for one-day games.[26]

The product in the professional sports industry has been defined as ‘the game, weighted by the number of paying customers who attend’.[27] Moreover, recent research shows that the attendance at one-day and three-day games is significantly influenced by the current ranking of a team in its competition, or ‘team performance and title chances’.[28] Obviously, all the tactical nuances of the game of cricket cannot adequately be captured in a single production function, but this study at least provides some evidence of how teams might achieve that level of performance and that degree of playing success in what are manifestly two very different forms of cricket. Although the approach adopted might be criticised for being narrowly academic, it offers a clear insight into the relative importance of batting and bowling, team strategy and team selection free from the euphoria that surrounds international sport.

NOTES

1. The authors wish to thank Paul Stewart, for both data collection and useful comments on cricket strategy; and Warwick Larkins and the Rev. Donald Phillips for providing access to published material.
2. G.W. Scully, 'Pay and Performance in Major League Baseball', *American Economic Review* 64 (1974), 915-930; J.H. Zak, C.F. Huang and J.J. Siegfried, 'Production Efficiency: The Case of Professional Basketball', *Journal of Business* 52(1979), 379-392; C.F. Zech, 'An Empirical Estimation of a Production Function: The Case of Major League Baseball', *American Economist* 25 (1981), 19-33; F.A. Scott, J.E. Long and K. Somppi, 'Salary Vs. Marginal Revenue Product under Monopsony and Competition: The Case of Professional Basketball', *Atlantic Economic Journal* 13 (1985), 50-59; J.C.H. Jones and W.D. Walsh, 'The World Hockey Association and Player Exploitation in the National Hockey League', *Quarterly Review of Economics and Business* 27 (1987) 87-101; M.D. Ackers and T.E. Buttross, 'An Actuarial Analysis of the Production Function of Major League Baseball', *Journal of Sports Behavior* 11 (1988), 99-112.
3. J.A. Schofield, 'Production Functions in the Sport Industry: An Empirical Analysis of Professional Cricket', *Applied Economics* 20 (1988), 177-193.
4. E.I. Bairam, J.M. Howells and G.M. Turner, 'Production Functions in Cricket: The Australian and New Zealand Experience', *Applied Economics*, forthcoming.
5. S. Rottenberg, 'The Baseball Players' Labor Market', *Journal of Political Economy* 64 (1956), 255.
6. E.I. Bairam, 'Functional Form on the Elasticity of Substitution: A New CES Production Function', *Economics Discussion Papers 8904* (1989), University of Otago.
7. Bairam, Howells and Turner, *op.cit*, p. 14.
8. Until the 1985/86 season, the top two teams at the end of the Shell Cup competition proper played a 'grand final'. Since points were not allocated to the eventual winner, this extra game is ignored in all calculations.
9. When weather conditions are unfavourable, the number of overs per innings may be reduced in order to get a result. If it is still impossible to 'manufacture' a result, the points are shared equally between the two teams.
10. Schofield, *op.cit.,* p. 180.
11. In each season in the period 1982/83 to 1987/88, New Zealand provincial teams played only eight three-day games and five one- day games. In contrast, teams in the English Country Championship played 20 to 24 three-day games and 16 one-day games in the John Player League.
12. M. Brearly, *The Art of Captaincy* (London: Hodder and Stoughton, 1985), p. 10.
13. Schofield, *op.cit*, p. 180.
14. *ibid.*
15. Bairam, *op.cit.*

16. It is worthwhile to note that $\lambda = 1$ and $\lambda = 0$, respectively, give the linear and log-linear models introduced and tested by Schofield *op.cit.*, p. 179.
17. This also implies that the new CES function introduced here has an advantage over conventional specifications of the CES production function because, unlike the latter, it does not make *a priori* assumptions about the functional relationship between inputs and output. See Bairam, *op.cit.*
18. K.J. White, 'A General Computer Program for Econometric Methods - SHAZAM', *Econometrica* 46 (1978), 239-240.
19. The lambda values in Tables 1 and 2 range between 0.95 and 1.00 and 0.91 and 1.03 respectively.
20. It is conceded that taking wickets can be a contributory factor in helping to restrict the opposition's run rate. However, the tactical importance of defensive bowling can be gauged from the fact that a team can win a one-day game without taking a single opposition wicket.
21. The most expensive bowling in Shell Cup cricket was in the 1982/83 season when CM Presland, Northern Districts, bowled 10 overs for 93 runs. One can assume that the captain would have preferred to use another bowler, but had no option but to continue with Presland until his allotted overs had been completed.
22. Compare this, too, with recent discussion on the appropriate formula for team selection for one-day games in Australia summarised by Philip Derriman in the *Sydney Morning Herald* (December 30, 1989).
23. Given the nature of the one-day game, it is often forgotten that specialist bowlers can make useful contributions to team totals, but specialist batsmen contribute little, or nothing, to bowling. Of current New Zealand players, only seven have scored 50 runs or greater on five or more occasions, and one of these is a bowler. A front-line bowler, NA Mallender, Otago, was fifth in the overall batting averages for the 1986/87 season and second in 1987/88.
24. Schofield, *op.cit.*, p. 188.
25. Unlike England and New Zealand, the best strategy-mix in the four-day Sheffield Shield competition is attacking batting and defensive bowling,and bowling is nearly 25 percent more important than batting. This is due to the fact that playing conditions make it much easier for batting to dominate bowling and bowling is forced into the same defensive and containment role as in one-day cricket. Bairam, Howells and Turner, *op.cit.*, pp. 11-12, l5-16.
26. It should be noted that it is bowling strategy that is important, not the type of bowler. Spin bowlers and faster bowlers can fit into an attacking or defensive game plan. One of the authors, who has played test cricket for New Zealand, has argued that the West Indian fast bowlers are particularly useful in one-day cricket because batsmen without proper technique find it difficult to score from the constant barrage of short-pitched balls. Although popularly perceived as attacking bowlers, they actually perform a special defensive role.
27. S. Rottenburg, 'The Baseball Players' Labor Market', Journal of Political Economy 64 (1956), 255.
28. J.A. Schofield, 'The Demand for Cricket: The Case of the John Player League', *Applied Economics* 15 (1983), 295.