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RANKING INTERNATIONAL LIMITED-OVERS CRICKET TEAMS USING A WEIGHTED, HETEROSKEDASTIC LOGISTIC REGRESSION WITH BETA DISTRIBUTED OUTCOMES

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Abstract. A regression-based ranking method is developed and applied to international limited-overs cricket, using a database of matches played between September 1999 and December 2007. The structure employed is a generalised linear model with logistic link function and beta distributed outcomes and is used to estimate team strength parameters which in turn yield ranking scores. The outcome variable for the regression is a newly proposed measure of the margin of victory based on the Duckworth-Lewis methodology. The model uses Weibull weighting to discount the impact of matches played in the past and incorporates a heteroskedastic structure to account for the potentially skewing effects of uncommonly large victories. Finally, the model is flexible enough to allow examination of the effects of other factors such as home ground advantage.

Keywords: Duckworth-Lewis Method, Generalised Linear Model, Relative Margin of Victory.

INTRODUCTION

Who's Number One? Sports pundits, participants and enthusiasts alike are obsessed with answering this question and, more generally, with rankings of all kinds. Often, the methods used to arrive at the answers are based on nothing more than "expert opinion" or simple statistics such as team win-loss records. While such subjective approaches lead to enthusiastic and revealing debate, they typically reveal more about the debaters than the actual answer to the question of accurate rankings. Of course, the appropriateness of any ranking system depends on the use to which the resultant ranks will be put. If the intent, as it often is, is simply to create a kind of on-going or annual competition, the winner of which will be the best performed team in the year, then detailed, objective methodology is perhaps less crucial and methods which are simple and intuitive may be the best approach. However, more and more in international sports, "official" rankings are being used for activities which involve monetary outcomes, such as seeding international tournaments, and in these circumstances it seems important to ensure an objective ranking which is based on true team strengths.

In this paper, an objective methodology for ranking international limited-overs cricket teams is developed. The methodology will be general enough that it may be modified to apply to other sports; however, limited-overs cricket is a nice starting point as there are relatively few nations which play the sport at international standard. In addition, as will be discussed in more detail subsequently, the relative margin of victory for any match can be meaningfully defined. This latter issue is of paramount importance if an objective ranking methodology is to be developed which incorporates all the information available in the history of results of any given sporting competition. In particular, an objective ranking methodology should incorporate all the information inherent in:

- The results of all matches in the competition, suitably discounted according to how long ago they occurred;
- The inter-relationships between head-to-head results and results between common opponents when determining relative rankings of individual teams; and,
- The relative margins of victory in matches.

The first two of these criteria lend themselves quite nicely to a weighted regression approach, with match results as the outcome variable, team strengths as the model parameters and weights determined according to the amount of time elapsed since each match has been played. The final of the three criteria listed above is crucially important from the perspective of determining rankings for the purpose of assessing true team strength. A method based only on results would always yield the same change in rankings after incorporating a new result regardless of the margin of victory, implying that should a very low ranked team lose to a very high ranked team, but only by a small margin, this would have the same effect as if the lower rank team had been defeated convincingly. While such a focus purely on result may be sensible from the perspective of a "ranking competition", it seems clear that if a low ranked team looses narrowly to a high ranked opponent, this should be taken to indicate an improvement in the lower ranked team, and ought to be reflected in an increase in standing. A methodology based solely on win-loss outcomes would, by its nature, indicate that any loss would result in a decrease in standing.

In the remainder of the paper, a measure of relative margin of victory suitable for limited-overs cricket is introduced, based on the famous Duckworth-Lewis methodology (1998, 2004), and a ranking based on applying a weighted generalised linear model incorporating beta distributed errors to the victory margins is developed and applied to a database of the results of the 12 major limited-overs cricketing nations: Australia, Bangladesh, England, India, Ireland, Kenya, New Zealand, Pakistan, South Africa, Sri Lanka, the West Indies and Zimbabwe. Modifications to the regression structure to incorporate various desirable features into the ranking mechanism are also discussed. Similar methods have been investigated by de Silva et al. (2001) as well as Clarke and Allsopp (2001) and, where appropriate, comparisons with their work are made.

A MEASURE OF VICTORY MARGIN IN LIMITED-OVERS CRICKET

Unlike many international sports, the pattern of play in limited-overs, or one-day international (ODI) cricket does not entail each team undertaking their offensive and defensive activities in a dynamic flow throughout the game. Instead, ODI cricket playing structure consists of two batting innings, one for each team, played consecutively and during which the batting team compiles its score of runs. Each batting innings continues until either the completion of a fixed number of overs, usually fifty, or the loss of ten wickets, or (in the case of the team batting second) the number of runs scored is sufficient to ensure victory, whichever occurs first. This structure, whereby each team undertakes its entire offensive activity contiguously, makes it particularly unique among high profile international sports and also makes a determination of the margin of victory for a match complex. If the team batting first wins the match then, assuming that the match was uninterrupted, the margin of victory is typically determined by the difference in the number of runs scored by the two teams. However, if the team batting second wins, then their innings ends as soon as they have scored enough runs, and thus their margin of victory is typically stated in terms of either the number of wickets or the number of overs (or both) still remaining when they achieved victory.

This asymmetry in the reporting of victory margin is further compounded by the fact that the outcomes of matches interrupted by weather or other circumstances are determined using a method developed and then further improved by Duckworth and Lewis (1998, 2004). Fortunately, the added complication of the Duckworth-Lewis (D/L) methodology also allows for a sensible way to develop a symmetric and practical definition for the margin of victory in ODI matches. The essence of the D/L method is "scoring resources". At any stage of a batting innings, the D/L method uses both the number of overs and the number of wickets remaining to determine the proportion of scoring resources still available. The primary use of the D/L method is to determine the proportion of scoring resources which are lost due to interruptions, so that appropriate comparison of scores from the two innings can be made to determine a winner. However, the resource calculations can also help determine a margin of victory. In particular, one sensible method of determining the margin of victory is to calculate the proportion of available resources which the winning team did not need. In this way, the size of a victory can be determined in a symmetric fashion regardless of whether the team batting first or the team batting second wins.

To implement this margin of victory calculation, define S_1 and S_2 to be the runs scored by the team batting first and the team batting second, respectively. Similarly, let U_1 and U_2 be the amount of their available scoring resources actually utilised by each team, and let M_2 be the total resources available to the team batting second (the total resources available to the team batting first is always equal to U_1), as determined by the D/L methodology. For details of calculating resources using the D/L method, see Duckworth and Lewis (2004); however, for clarity, note that D/L resources are calculated on a proportional scale where unity is equivalent to the resources associated with a fifty over innings and ten available wickets, so that in an uninterrupted match U_1 and M_2 will always be 1 and U_2 will be 1 whenever the team batting first wins (or the game is tied) and less than 1 whenever the team batting second wins. If the team batting second wins the match, their margin of victory, V, can then be calculated as:

$$V = \frac{M_2 - U_2}{M_2},$$

which is the proportionate amount of their unused resources. Alternatively, if the team batting first wins, then the proportion of unnecessarily used resources (recall that the team batting first will always use all of its allotted resources, as it does not know beforehand how much it will ultimately need) can be calculated as:

$$V = \frac{U_1 - R_1}{U_1},$$

where R_1 is the amount of resources actually needed for the team batting first to have achieved victory. To achieve victory, the team batting first needs only to have scored more runs than the team batting second would have scored given an equivalent amount of resources. Thus, R_1 is the solution to the equation:

$$\left(\frac{S_1}{U_1}\right) R_1 = \left(\frac{S_2}{U_2}\right) U_1,$$

which implies $R_1 = (S_2 U_1^2)/(S_1 U_2)$.

To simplify the calculations, note that the D/L method "par score" at any point in the second innings is the number of runs the team batting second would need to have scored to make the match a tie were it terminated at that point. The value of the par score at the end of the second innings is readily calculated as $P = S_1 U_2 / U_1$ (though, typically, P is rounded to the nearest whole number). Using this relationship, the victory margin for a team batting first can be re-written as:

$$V = \frac{U_1 - R_1}{U_1} = \frac{S_1 U_1 U_2 - S_2 U_1^2}{S_1 U_1 U_2} = \frac{P - S_2}{P}.$$

Alternatively, if the team batting second wins, their score is equivalent to the victory target (at least approximately, as the actual score of the team batting second may be a few runs larger than the victory target, depending on the number of runs scored on the winning scoring stroke), which itself is essentially the par score associated with the maximum resources available to the team batting second, $S_1 M_2 / U_1$. Thus, it is seen that $S_2 \approx S_1 M_2 / U_1$ and the victory margin in the case that the team batting second wins is then given by:

$$V = \frac{M_2 - U_2}{M_2} = \frac{S_1 M_2 - S_1 U_2}{S_1 M_2} = \frac{S_2 - P}{S_2}.$$

Combining the two cases yields:

$$V = \frac{|P - S_2|}{\max\{P, S_2\}}.$$

Finally, for the sake of using a single value for all matches, the signed victory margin is defined as:

$$D_1 = \frac{P - S_2}{\max\{P, S_2\}},$$

and will be referred to as the *Relative Resource Differential* (RRD). Note that D_1 is positive if the team batting first wins and negative otherwise; in other words, the RRD is a margin of victory for the team batting first, a negative value indicating the margin of their loss. For the sake of completeness, note that an alternative measure of victory margin defined in terms of the "effective" runs differential

$$\frac{S_1}{U_1} - \frac{S_2}{U_2} \approx D_1 \max\left\{\frac{S_1}{U_1}, \frac{S_2}{U_2}\right\}.$$

has been previously proposed, debated and even employed to assess relative team strength (Clarke & Allsopp, 2001, 2002; de Silva et al., 2001; Duckworth & Lewis, 2002). The RRD is preferred here for modelling team strengths since it inherently adjusts for the overall scoring rate in the match. In other words, the RRD recognises that a 50 run victory is less substantial (at least in terms of resources saved) when the final score was 350 to 300 than when the final score was 250 to 200.

RANKING INTERNATIONAL LIMITED-OVERS CRICKET TEAMS

To estimate the team strength of the 12 major ODI teams, a database of all results of matches between these teams from the start of the 1999 Cricket World Cup until the end of the 2007 calendar year is investigated. This database consists of 1066 matches and the breakdown of head-to-head games, including the tabulation of which team batted first and which batted second, is given in Table 1.

Table 1: Number of Head-to-Head ODI Matches by Team and Batting Order (September 1999 – December 2007)

Batted First	Batted Second											
	AUS	BAN	ENG	IND	IRE	KEN	NZL	PAK	SAF	SRL	WIN	ZIM
AUS	–	3	10	16	0	0	24	11	18	13	15	8
BAN	9	–	7	5	0	2	6	4	5	8	4	16
ENG	15	1	–	17	2	0	8	10	7	11	6	9
IND	17	5	12	–	0	5	11	17	15	12	17	15
IRE	1	1	0	1	–	1	0	0	1	1	1	1
KEN	3	6	2	4	0	–	0	3	4	1	2	7
NZL	13	4	4	12	1	1	–	12	16	12	12	5
PAK	13	8	9	19	1	1	19	–	18	15	13	10
SAF	12	3	10	14	1	3	13	12	–	12	10	9
SRL	11	9	13	20	0	2	14	21	18	–	8	12
WIN	7	7	9	15	0	3	7	13	11	6	–	15
ZIM	7	13	14	10	0	3	5	5	11	9	15	–

The small numbers of matches between some of the teams means using the inter-relationship information contained in the outcomes of matches between common opponents is critical in accurately assessing team strengths, and this information is directly used in a regression approach. A beta regression is employed as described in the following, applied to the relative resource differential (RRD) values, suitably transformed to

$$Y = \tfrac{1}{2}\left(D_1 + 1\right),$$

so that the outcomes take values in the unit interval. Note that Y values less than 0.5 correspond to losses for the team batting first and Y values greater than 0.5 to their wins.

Weighted Logistic Regression with Beta Distributed Outcomes

Consider a random quantity, Y, whose outcomes are values within the unit interval. A convenient model for the distribution of Y is given by the beta family. Specifically, the beta family consists of a collection of distributions with support on the unit interval and probability density functions of the form:

$$f(y;\mu,\phi) = \frac{\Gamma(\phi)}{\Gamma(\phi\mu)\Gamma\{\phi(1-\mu)\}} y^{\phi\mu-1}(1-y)^{\phi(1-\mu)-1},$$

where $\Gamma()$ is the gamma function, μ is the expectation of the distribution and the variance is $\mu(1-\mu)/(1+\phi)$. As such, ϕ is a measure of dispersion of the distribution, small values of ϕ corresponding to large dispersions.

Regressions based on a generalised linear model with the beta distribution as the error structure have been used recently in various areas (Ferrari & Cribari-Neto, 2004; Smithson & Verkuilen, 2006). To model team strengths, a beta regression model for the RRD values, D_1, is employed with mean structure of the form:

$$E\left(Y_{ij}\right) = E\left\{\tfrac{1}{2}\left(D_{1,ij} + 1\right)\right\} = \mu_{ij} = g^{-1}\left(\beta_i - \beta_j\right)$$

where $D_{1,ij}$ is the victory margin for a match between teams i and j in which team i bats first and $g()$ is a suitable *link* function. There are many possibilities for the link, the only requirements being that the function map the unit interval to the entire real line and that it is invertible; however, the common choices are the probit function based on the inverse of the cumulative distribution function of the standard normal distribution, the complementary log-log function, $g(x)=\ln\{-\ln(1-x)\}$, and the logistic function $g(x)=\ln\{x/(1-x)\}$. The latter is chosen for what follows for reasons discussed later. Note that, if the link is the identity function, the margin of victory used is the "effective" runs difference noted above and the beta error structure is replaced by a normal error structure, the model reduces to that of de Silva et al. (2001) as well as Clarke and Allsopp (2001) (with their "first innings advantage" parameter, h, set to 0). As for those models, a parameter constraint is needed here, and so the β_i's will be required to sum to zero to ensure identifiability.

Once a link function is chosen, the estimation of the parameters, $\beta_1, \ldots, \beta_{12}$, is accomplished using maximum likelihood methodology. However, for the application here, the information associated with matches must be discounted according to their age. In general, this can be accomplished quite simply by defining the parameter estimates to be the maximising values of the weighted log-likelihood function:

$$l(\beta_1, \ldots, \beta_{12}, \phi) = \sum_{k=1}^{n} w_k \ln\left[f\left\{ Y_{i_k j_k}; g^{-1}\left(\beta_{i_k} - \beta_{j_k}\right), \phi \right\} \right]$$

where i_k is the team batting first in the k^{th} match of the dataset, j_k is the team batting second and the w_k's are suitably defined weights. While there are many possible choices for weights, for what follows a choice is required that is based on the age of a match, A_k, and takes values of essentially unity for matches less than a certain age and then decreases steadily until matches beyond a certain age have essentially no contribution. One choice of weights with these features is based on the survival function of the Weibull distribution, $w_k = \exp(cA_k^{\,d})$, for some choice of positive constants c and d. Table 2 shows the values of the Weibull survival function weights for different choices of the constants and matches of various ages.

Table 2: Weibull weights for matches of various ages

Constants	Age of match (in years)							
	1	2	3	4	5	6	7	8
c = 0.01, d=4	0.990	0.852	0.445	0.077	0.002	0.000	0.000	0.000
c = 0.005, d=6	0.995	0.726	0.026	0.000	0.000	0.000	0.000	0.000
c = 0.015, d=3	0.985	0.887	0.667	0.383	0.153	0.039	0.006	0.000

In the analysis that follows, the values c=0.01 and d=4 are used, which indicate that matches played within 1 year of the date on which the model is fit are given a weight of essentially unity and matches which are 5 years old or more are given essentially no weight at all. While other choices are possible, the effect on ranking scores of varying values of c and d was investigated and found to be minimal (results not presented).

A Ranking of International Limited-Overs Cricket Teams

The logistic link structure is used for the beta regression model employed here. The expected outcome for a match in which team i bats first and team j bats second is then defined as:

$$\mu_{ij} = \frac{\exp(\beta_i - \beta_j)}{1 + \exp(\beta_i - \beta_j)}.$$

This mean structure yields values less than 0.5 if the team batting second has a larger strength parameter and values greater than 0.5 if the team batting first has the larger strength parameter. Also, some algebra shows: $\mu_{ji} = 1 - \mu_{ij}$. Thus, the chosen mean structure is symmetric about 0.5, as it should be in this case, as the only difference between μ_{ij} and μ_{ji} is the order in which the teams bat, and the expected outcome should therefore reflect that the expected RRD should simply change sign. This symmetric structure is not sustained by the other common link choices, either the probit or the complementary log-log functions.

Once estimates of the β's are obtained, they may be used to derive ranking scores and a standings table. To do so, the expected transformed victory margin, Y, for team i against a generic opponent is used:

$$R_i = \frac{\exp(\beta_i)}{1 + \exp(\beta_i)}.$$

For the sake of simplicity, interpretability and comparison with other methods, these values are scaled by a factor of 200 and then round to the nearest tenth of an integer. This means that a team whose average result is a tie (which does not necessarily imply that they win half their games) has a ranking score of 100.

Using this ranking scheme (and the Weibull weighting according to the age of matches described previously, with constants c=0.01 and d=4), the standings as of the end of the 2007 calendar year are:

Table 3: ODI Team Rankings using Basic Beta Regression Model (as of 1/1/2008)

Team	Ranking Score	Team	Ranking Score	Team	Ranking Score
Australia	125.5	India	108.4	Bangladesh	83.4
South Africa	118.1	England	106.4	Ireland	79.6
New Zealand	117.2	West Indies	105.2	Zimbabwe	74.6
Sri Lanka	115.0	Pakistan	105.1	Kenya	63.2

Over-dispersion and the Effect of Uncommonly Large Victory Margins

A common concern raised over using margins of victory as the basis for rankings is that either a single or relatively few unusually large wins or losses will unduly affect the team strength parameters. One way to counteract this effect is to employ a model structure which deals not just with the mean structure, but with the variation structure as well. If each team is assigned both a strength parameter and a volatility parameter, then a few large victories will tend to increase the volatility parameter estimate, and thus insulate to some degree the strength parameter from the adverse effects of uncommonly large margins.

For beta regression models, heteroskedastic structure may be incorporated using volatility parameters to model the relationship between individual outcomes and the dispersion parameter, ϕ. Specifically, the dispersion structure for the team strength model is defined as: $\phi_{ij}=h^{-1}(\gamma_0+\gamma_i+\gamma_j)$, where γ_i and γ_j are the volatility parameters for teams i and j, respectively, and $h()$ is a suitable link function. As for the mean structure, the volatility parameterisation requires a constraint to ensure identifiablility, so the γ_i's will be required to sum to zero. The estimated strength and volatility parameters are then the values which maximise:

$$l_{\text{het}}(\beta_1,\ldots,\beta_{12},\gamma_0,\gamma_1,\ldots,\gamma_{12})=\sum_{k=1}^{n} w_k \ln\left[f\left\{D_{1,i_k j_k};g^{-1}\left(\beta_{i_k}-\beta_{j_k}\right),h^{-1}\left(\gamma_0+\gamma_{i_k}+\gamma_{j_k}\right)\right\}\right]$$

The ranking scores are determined as before, using the estimated team strength parameters, $\beta_1,\ldots,\beta_{12}$. For the analysis here, the volatility link structure $h(x) = \ln(x)$ is used. While all that is required of the volatility link function is that it be invertible and map the positive half-line to the entire real line, the logarithmic choice is the simplest and most common. The resultant ranking scores from fitting this model are given in Table 4.

Table 4: ODI Team Rankings using Heteroskedastic Beta Regression Model (as of 1/1/2008)

Team	Ranking Score	Team	Ranking Score	Team	Ranking Score
Australia	124.9	India	108.1	Bangladesh	83.0
South Africa	118.4	England	106.7	Ireland	80.8
New Zealand	116.9	Pakistan	105.6	Zimbabwe	73.8
Sri Lanka	113.5	West Indies	105.4	Kenya	64.6

The differences between these ranking scores and those derived from the model without heteroskedastic structure are small; however, there is one reversal in ranking order with Pakistan moving ahead of the West Indies. A likelihood ratio test indicates that the inclusion of heteroskedastic structure does not significantly improve the model fit (LRS = 12.81 on 11 degrees of freedom, p-value of 0.306). Nevertheless, maintaining it in the model is recommended so that the potential for adverse effects due to extremely large victories is addressed. Indeed, it so happens that the last match in the dataset used for this analysis was played on December 31, 2007 between New Zealand and Bangladesh. New Zealand won the match by bowling out Bangladesh for 93 runs and then scoring 95 runs in 6 overs, resulting in a victory margin of $D_1 = -0.937$, the largest (in absolute value) of any match in the database. The changes in ranking scores under the two models, homoskedastic and heteroskedastic, as a result of this match are shown in Table 5.

Table 5: Change in Ranking Scores as a Result of the Match on December 31, 2007

	Ranking Score from Basic Model		Ranking Score from Heteroskedastic Model	
	Without 31/12/07 Match	*With 31/12/07 Match*	*Without 31/12/07 Match*	*With 31/12/07 Match*
New Zealand	115.3	117.2	115.8	116.9
Bangladesh	85.4	83.4	84.5	83.0

The effect of the massive victory is moderated by the heteroskedastic volatility structure. In this sense, the heteroskedastic structure down-weights large victories or, equivalently, gives more weight to any victory. In other words, this new model gives a "bonus" for simply achieving victory.

DISCUSSION

The regression-based methodology described here was designed for international limited-overs cricket. However, the structure may be applied to other sports. All that is required is a sensible definition of a relative margin of victory. Of course, this may not be easy. Cricket is unique in many ways, and the Duckworth-Lewis methodology made the definition of the RRD possible. Typically, cricket scores are large enough that relative margins of victory are meaningful. By comparison, an appropriate parallel concept may be more difficult to define in other sports. For example, in rugby, it is difficult to decide whether a 6-3 victory is more comparable to a 60-30 victory or a 33-30 victory. Nevertheless, given an appropriate definition of relative margin of victory, the model structure defined here will provide objective ranking scores.

The mean and volatility model structures are also flexible enough to allow inclusion of components to address other aspects of matches which may affect outcomes and should be accounted for in assessing team strength. For example, a factor for home ground advantage may be incorporated into the mean structure as:

$$\mu_{ij} = g^{-1}\left(\beta_i - \beta_j + \kappa\delta_{ij}\right)$$

where κ is the home ground effect and $\delta_{ij} = 1$ if team i is the home team, $\delta_{ij} = -1$ if team j is the home team and $\delta_{ij} = 0$ if the match is played at a neutral site. Table 6 shows the ranking scores from the heteroskedastic beta regression model including this home ground advantage factor.

Table 6: ODI Team Rankings using Heteroskedastic Model with Home Advantage (as of 1/1/2008)

Team	Ranking Score	Team	Ranking Score	Team	Ranking Score
Australia	125.5	India	107.5	Bangladesh	83.2
South Africa	118.0	England	106.6	Ireland	80.3
New Zealand	117.0	Pakistan	105.6	Zimbabwe	73.3
Sri Lanka	114.4	West Indies	105.3	Kenya	64.8

The estimated home ground advantage factor is κ=0.101 (which is statistically significant, p=0.002). Clearly, teams are aided by playing in familiar surroundings, and this ought to be accounted for when estimating team strengths. For example, India is far more successful at home, and thus their ranking score under this new model has decreased. Other effects of interest are readily examined in a similar way; such as, factors for the potential effects of batting first, as in Clarke and Allsopp (2001), or winning the initial coin toss.

As noted previously, one crucial aspect of a sensible ranking system is that it is not overly affected by a few very large victories. In other words, there should be something sacrosanct about a victory, so that the effect on ranking of the scoring play which achieved victory is larger than for any other scoring play. To a certain extent, the heteroskedastic structure provides this aspect. However, it may be the case that more is needed. One way of including such an aspect into the model is the use of modified or penalised likelihood, which could give increased likelihood to the larger parameters even in the case of a relatively narrow victory.

Finally, in closing, a comparison is made between the rankings developed here and the official ICC ODI rankings, based on a method developed by David Kendix. Details of the Kendix method can be found on the ICC's web-site (**www.icc-cricket.com**); essentially, though, the method is based on awarding "ranking points" to each team involved in a given match, and then creating a standings table based on teams' average ranking points per match. Relative team strengths are incorporated in the Kendix method by allowing the ranking points awarded for any match to depend on the current ranking of the opponents, so that defeating a lower ranked opponent provides fewer ranking points than defeating a higher ranked opponent. The weighting of matches based on age is accomplished by giving full weight to any match which occurs between the ranking date and the preceding August 1st, half weight to any match which occurs in the 12 months prior to the preceding August 1st and one-quarter weight to matches occurring in the 12 months prior to that. The Kendix method does not account for margins of victory in its ranking procedure. The major benefit of the Kendix method is its relative simplicity. Its calculation scheme makes it simple to see how the outcome of any match will affect the rankings. By comparison, the method developed here makes the effect of the outcome of a single match less obvious (though, simply fitting the model with and without the result of the match in question will clearly indicate its ultimate effect on the rankings). Moreover, for the Kendix method, the result of any match only affects the ranking points of the two teams involved, whereas the regression-based rankings allow the outcome of any match to potentially affect the entire ranking table, as it fully incorporates the "common opponent" information that each result entails. Also, the smoothly varying weightings provided by the Weibull survival function structure avoids the discontinuity associated with the method employed by the Kendix rankings, which may lead to notable shifts in team rankings each August. The ICC ODI ranking table at the end of the 2007 calendar year is given in Table 7 below.

Table 7: Official ICC ODI Team Rankings (as of 1/1/2008)

Team	Ranking Score	Team	Ranking Score	Team	Ranking Score
Australia	130	Sri Lanka	108	Bangladesh	47
South Africa	124	Pakistan	107	Ireland	28
New Zealand	112	England	107	Zimbabwe	20
India	110	West Indies	100	Kenya	0

The team ordering is in close agreement with the results presented here. However, the gaps between the ranking scores are noticeably different. New Zealand is nearer South Africa in the rankings presented here and Ireland is nearer Bangladesh, and both are nearer the West Indies. The difference in rankings at the lower end of the table is partly a reflection of the fact that these teams play less frequently and the Kendix method uses only matches which are no more than three years old. In addition, investigation of the effect of individual matches indicates that the Kendix method is more volatile in its ranking scores, and the outcome of a few matches can make dramatic changes to the ranking scores, which is ironic given that margins of victory were not included in the method in part because of their perceived potential for just such an effect.

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References

Clarke, S.R. and Allsopp, P. (2001) Fair measures of performance – the world cup of cricket. *Journal of the Operational Research Society*, **52:** 471-479.

Clarke, S.R. and Allsopp, P. (2002) Response to Duckworth and Lewis, comment on Clarke and Allsopp (2001), Fair measures of performance – the world cup of cricket. *Journal of the Operational Research Society*, **53:** 1160-1161.

de Silva, B.M., Pond, G. and Swartz, T. (2001) Estimation of the magnitude of victory in one-day cricket. *Australian and New Zealand Journal of Statistics.* **43:** 259-268.

Duckworth, F.C. and Lewis, A.J. (1998) A fair method of resetting the target in interrupted one-day cricket matches. *Journal of the Operational Research Society.* **49:** 220-227.

Duckworth, F.C. and Lewis, A.J. (2002), Comment on Clarke and Allsopp (2001), Fair measures of performance – the world cup of cricket. *Journal of the Operational Research Society*, **53:** 1159-1160.

Duckworth, F.C. and Lewis, A.J. (2004) A successful operational research intervention in one-day cricket. *Journal of the Operational Research Society.* **55:** 749-759.

Ferrari, S. and Cribari-Neto, F. (2004) Beta regression for modeling rates and proportions. *Journal of Applied Statistics.* **31:** 799-815.

Smithson, M. and Verkuilen, J. (2006) A better lemon squeezer? Maximum likelihood regression with beta-distributed dependent variables. *Psychological Methods.* **11:** 54-71.