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Effort Levels in Contests: An Empirical Application of the Tullock Model

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Abstract

Empirical applications of the Tullock contest model are rare, due in part to the non-observability of effort. This paper presents an application of the standard Tullock model in a setting where effort can be observed and explained. A simple contest model is used to predict levels of effort in English soccer, with data on fouls and yellow and red cards used to reflect the effort of teams. Effort levels are found to be higher in matches between evenly balanced teams, and in matches with implications for end-of-season outcomes. The results suggest that the teams' effort levels are strategic complements.

JEL-Classification: L83.

Keywords: Tullock contest, team sport, strategic complements.

Effort Levels in Contests: An Empirical Application of the Tullock Model

1. Introduction

Tullock's (1980) contest model is a standard tool in economics. In a winner-take-all contest, the ex ante probability of winning depends positively on your effort and negatively on your opponent's effort. Numerous papers have used the Tullock contest model to describe rent-seeking behavior or success in tournaments (e.g., Lazear and Rosen, 1981; Nitzan, 1991, 1994). In general, however, the Tullock model does not predict whether effort is a strategic substitute or complement in the sense of Bulow et al. (1985); this depends upon the payoff structure.

Empirical applications of the standard Tullock model are rare, due in part to the non-observability of effort. For example, data on bribes and the transfer of intangible assets in rent-seeking contests may be unobtainable. However, team sports offer a potentially fruitful setting for testing the standard Tullock model with non-experimental data, since effort can be observed and explained. Jia (2006), for example, uses data from US professional basketball to show that match outcomes depend on the contributed effort of the teams (where effort is proxied with on-court salary data), but there is no attempt to explain equilibrium levels of effort.

In this paper a simple Tullock contest model is used to predict levels of effort. The application is presented in the context of English professional soccer. In this setting, one important influence on the probability of winning a contest (apart from underlying team quality) is the contributed effort of the teams. By working hard to press the opposition and make tackles, teams will eventually commit fouls and receive yellow and red cards. Therefore, effort can be usefully measured by the numbers of fouls committed by the home and away teams, and the numbers of yellow and red cards awarded against each team.[1]

The remainder of this paper is organized as follows. Section 2 develops the theoretical model. Section 3 describes the data and the empirical model. Section 4 reports the empirical results; and Section 5 concludes.

2. Theoretical Framework

This section develops a standard contest model for soccer match outcomes. Before the match, each manager (coach) decides independently on the conduct of his team: specifically, whether the team will work hard to tackle (and press) players of the opposition. Effort is measured by a continuous variable e_i, where i=1, 2 denotes the home and away teams. Greater effort carries a cost, because it increases the probability that a player receives a caution (yellow card) or is dismissed (red card).[2] The marginal cost of effort, denoted c, is assumed to be constant and identical for all teams.

Both teams' effort levels influence the probabilities for the match outcome. For simplicity, the theoretical model is developed by incorporating the following weighted sum of the home team's win probability and the draw probability into the teams' expected payoff functions: $p(e_1, e_2)$=prob(home win) +0.5prob(draw). $p(e_1, e_2)$ is the home team's success probability, and $1 - p(e_1, e_2)$ is the away team's success probability.[3]

The teams are assumed to be heterogeneous in underlying quality, and an asymmetric contest model is required (Corchon, 2000). The teams' prior success probabilities reflect the relative quality of the teams and home-field advantage, but they do not reflect the teams' choices of e_1 and e_2. The absolute quality if team i, which is common knowledge before the match, is denoted β_i. Home-field advantage, arising from the support the home team receives from the crowd and from any possible refereeing bias (Dawson et al., 2007), is represented by a parameter h. The home team's prior success probability is

$$r = p(0,0) = \frac{\beta_1 + h}{\beta_1 + \beta_2 + h} \tag{1}$$

Positive effort levels by either team influence the success probabilities, such that

$$p(e_1, e_2) = \frac{e_1 r}{e_1 r + e_2(1-r)} \tag{2}$$

The expected payoffs for teams 1 and 2 are

$$\pi_1 = p(e_1, e_2)U_1 - ce_1, \quad \pi_2 = [1 - p(e_1, e_2)]U_2 - ce_2 \tag{3}$$

where U_i represents the gross payoff (before deducting the cost arising from greater effort) to team i from winning the match.[4] U_i depends on the importance of the match to team i. For example, U_i is large if team i is near the top of its divisional league table and in contention for the championship, qualification for European competition, or promotion to a higher division. U_i is also large if team i is near the bottom of its divisional table and in danger of relegation to the division below. U_i is small when team i is out of contention for any of these end-of-season outcomes.

The absolute team quality measures β_1 and β_2 are determined by the quality of playing talents, the ability of the managers, and the teams' tactical capabilities. All of these determinants may vary over time, even within a soccer season. Prior to each match, the team managers select e_1 and e_2 so as to maximize their teams' expected payoffs. The non-cooperative solution for the equilibrium levels of effort is

$$e_1^* = \frac{(1-r)rU_1^2U_2}{c(rU_1 + (1-r)U_2)^2} \qquad e_2^* = \frac{(1-r)rU_2^2U_1}{c(rU_1 + (1-r)U_2)^2} \tag{4}$$

From (4), the equilibrium levels of effort decrease with the marginal cost of effort. From contest theory it is well known that the response of the strategic variable (the level of effort) to a small change in the payoffs depends upon the levels of the payoffs. The partial derivatives of (4) with respect to the home team's win payoff U_1 are

$$\frac{\partial e_1^*}{\partial U_1} = \frac{2(1-r)^2 rU_1U_2^2}{c(rU_1 + (1-r)U_2)^3}, \qquad \frac{\partial e_2^*}{\partial U_1} = -\frac{(1-r)rU_2^2(rU_1 - (1-r)U_2)}{c(rU_1 + (1-r)U_2)^3} \tag{5}$$

Equivalent results can be derived for small changes in the away team's win payoff. In (5), $\partial e_1^* / \partial U_1$ is unambiguously positive. This leads to

Result 1: *An increase in the payoff from a win for either team will unambiguously increase that team's level of effort.*

The effect of an increase in the payoff from a win on the other team's level of effort is ambiguous. In (5), $\partial e_2^* / \partial U_1$ is positive if $(1-r)U_2 > rU_1$ and negative if $(1-r)U_2 < rU_1$, where rU_1 and $(1 - r)U_2$ are the two teams' expected prior payoffs.

By substituting (4) into (2), the equilibrium solution for the home team's success probability is

$$p(e_1^*, e_2^*) = \frac{\beta_1 + h}{\beta_1 + \beta_2(U_2/U_1) + h} \tag{6}$$

Comparing (6) with (1) leads to

Result 2: *The home team's equilibrium success probability is larger (smaller) than its prior success probability if the home team's win payoff is larger (smaller) than the away team's win payoff.*

Finally, the values of *r* at which the teams' levels of effort are maximized are derived from (4). The maximum value of e_1 is obtained when $r=U_2/(U_1+U_2)$, and the maximum value of e_2 is obtained when $r=U_1/(U_1+U_2)$. This leads to

Result 3: *If the teams' payoffs from a win are the same, the teams' effort levels are maximized when the match is evenly balanced after allowing for home-field advantage, in the sense that each team has a prior success probability of 0.5. If the teams' payoffs from a win are unequal, the teams' effort levels are maximized when the prior success probability of the team with the larger (smaller) payoff is below (above) 0.5.*

3. Data and Empirical Model

The data for the empirical analysis comprises all 12,216 matches played in the English Premier League (the Premiership) and the three divisions of the English Football League (currently known as the Championship, League One and League Two) during the six soccer seasons from 2001/02 to 2006/07 (inclusive). The data source is www.football-data.co.uk. The dependent variables in the empirical models are the numbers of fouls committed by each team per match, and the numbers of yellow and red cards awarded against each team per match.

Table 1 reports descriptive statistics. The sample means for the numbers of fouls awarded against the home and away teams are 12.4 and 13.1 per match, respectively. Although the number of fouls per match takes the form of count data, the number of cells appears sufficiently large to justify treating these data as continuous. Accordingly, the fouls equations are estimated as Seemingly Unrelated Regressions (SUR). The interdependence between the fouls committed by the home and away teams is captured by the contemporaneous correlation between the disturbances of the home and away team equations.

The sample means for the numbers of cards awarded against the home and away teams per match are 1.2687 and 1.6957 (yellow) and 0.0747 and 0.1198 (red), respectively. In this case the numbers of cells are small, necessitating the use of count data regression models. As Table 1 shows, the sample variances are similar to the sample means, which suggests that the Poisson distribution provides a suitable probability model. The yellow and red cards equations are estimated using a bivariate distribution obtained from the convolution of two univariate zero-inflated Poisson probability functions via the Frank copula (Lee, 1999).[5] The copula function contains a parameter that controls for interdependence between the cards awarded against the home and away teams. The bivariate cards regressions reported in

Section 4 express the log-mean number of cards for each team as a linear function of covariates that are defined below.

According to the theoretical analysis developed in Section 2, the teams' strategic choices for their levels of effort depend upon two factors: (i) differences between the payoffs from a win for each team; and (ii) the degree of balance or imbalance between the teams' prior success probabilities. Controls are included for (i) and (ii), and for one further non-strategic determinant of the levels of foul play: (iii) weaker teams that tend to spend more of the match defending are expected to commit more fouls and collect more cards than stronger teams that spend more time attacking.

In controlling for (i) above, it is assumed that the two teams' payoffs from a win may differ once a stage of the season has been reached at which some teams have dropped out of contention for championship, European qualification, promotion or relegation outcomes. The 0-1 dummy variable HSIG = 1 if the match is significant for end-of-season outcomes for the home team, and ASIG = 1 if the match is significant for the away team. The algorithm that determines whether the match is significant assesses whether it is arithmetically possible (before the match is played) for the team to win the championship, qualify for European competition, be promoted or be relegated, if all other teams currently in contention for the same outcome take one league point on average from each of their remaining fixtures.[6]

In order to control for (ii) and (iii) above, relative team quality is measured using HPROB=prob(home win)+0.5×prob(draw). HPROB corresponds to the variable *r*, the home team's prior success probability, in the theoretical model. A numerical value for HPROB for each of the N=12,216 sample matches is generated from the match results forecasting model described in full by Goddard (2005).[7] Included among the covariates of this model are HSIG and ASIG (as defined above), which control for the effect of incentives on the match result probabilities. In the present case, HPROB should reflect prior success probabilities, which depend upon the underlying quality of the two teams, but should not incorporate any incentives effects. Therefore in generating HPROB from the forecasting model, we reset the values of HSIG and ASIG to zero for the (out-of-sample) matches for which the forecasts are produced.

A convenient measure of the competitiveness of the match, or uncertainty of match outcome, is UNCERT = HPROB×(1–HPROB). UNCERT is maximized when HPROB=0.5. A positive relationship is expected between UNCERT and the numbers of fouls and cards awarded.

Finally, the estimations include controls for several other factors that might be expected to influence the number of fouls comitted and cards awarded. Individual soccer season dummy variables control for changes over time in the content and interpretation of the rules relating to foul play; referee fixed effects control for variation among referees in the propensity to award fouls and cards; and individual team fixed effects control for other unobservable differences between teams.[8]

4. Empirical Results

The estimation results are reported in Table 2. Column (1) reports the SUR estimations for the numbers of fouls committed, and columns (2) and (3) report maximum likelihood estimation results for the bivariate regressions for the numbers of cards awarded against the home and away teams.

The coefficients on HSIG in all three equations are positively signed (as expected) but insignificant; while the coefficients on ASIG are positively signed (as expected) and significant at the 5% level or lower, using one-tail tests. Therefore we find some evidence to support the hypothesis developed in Section 2 that the teams' strategies reflect the magnitudes of the payoffs. However, the tendency for effort to be lower when no end-of-season outcomes are at stake appears more pronounced when playing away from home than at home. A possible interpretation is that away teams tend to 'ease off' in unimportant end-of-season matches, but home teams, perhaps conscious of their own crowd's critical scrutiny, feel obliged to demonstrate maximum commitment at all times.

The coefficients on HPROB are negatively signed (as expected) in the equations for the home team, and positively signed (as expected) in the equtions for the away team. Two of the three coefficients on HPROB for the home team (in the fouls and the yellow cards equations) are significant at the 1% level, and all three coefficients on HPROB for the away team are significant (at the 1% level in the fouls equation, 5% level in the yellow cards equation, and 10% level in the red cards equation). These results indicate that weaker teams (as measured by the prior success probability) tend to commit more fouls and collect more cards than stronger teams.

Finally, the coefficients on UNCERT are positively signed (as expected) in every case. Two of the three coefficients on UNCERT for the home team (in the fouls and the red cards equations) are significant at the 5% level or below, and all three coefficients on HPROB for the away team are significant at the 5% level or lower. These findings are consistent with the hypothesis, developed in Section 2, that effort levels tend to be higher in matches involving teams that are evenly balanced than in matches where there is a large disparity between the quality of the two teams.

5. Conclusion

The Tullock contest model has been widely used in the contest theory literature. Although the standard Tullock model provides a number of testable predictions about the behavior of agents in winner-take-all contests, empirical applications have been rare. This paper has tested the implications of the Tullock model in a setting where effort can be observed and explained. Using data from English professional soccer, the effort of the teams is reflected in the numbers of fouls committed and the numbers of yellow and red cards awarded. The results show that effort levels tend to be higher in matches between evenly balanced teams, and away teams (in particular) tend to work harder to make tackles when end-of-season outcomes are at stake. The results suggest that the teams' effort levels are strategic complements.

Notes

[1] Teams that make more (less) effort to tackle the opposition can expect to commit more (fewer) fouls and collect more (fewer) yellow and red cards than teams that make less (more) effort. A foul in soccer is an unfair act by a player against an opponent which is deemed by the referee to contravene Law 12 of the Laws of the Game. If the referee judges the foul play to be serious he may decide that it warrants a disciplinary sanction (yellow or red card) in accordance with Law 12. A yellow card is awarded for less serious transgressions. There is no further punishment within the match, unless the player commits a second similar offence, in which case a red card is awarded and the player is expelled for the rest of the match (with no replacement permitted). A red card, also known as a sending-off or dismissal, is awarded for more serious offences and results in immediate expulsion (again, with no replacement permitted).

[2] A red card leads to a suspension, preventing the player from appearing in either one, two or three of his team's next scheduled matches. A player who accumulates five yellow cards in different matches within the same season also receives a suspension.

[3] This formulation ensures that the two teams' success probabilities sum to one, and by so doing simplifies the algebra without any loss of generality. The weight attached to prob(home win) in the definition of $p(e_1,e_2)$ is twice the weight attached to prob(draw). Therefore by assuming (below) that the teams' expected gross utility payoffs from the match are obtained by multiplying the utility value of a win by $p(e_1,e_2)$, it is assumed implicitly that the utility value of the draw is half the utility value of the win. In accordance with expected utility theory, under the league points system of three points for a win and one point for a draw, this set-up implies risk aversion on the part of team managers. Other weightings for the utility

values of the win and the draw can be accommodated by the model without affecting fundamentally any of the results that are derived below, but at the cost of introducing some additional algebraic complexity.

[4] Payoffs are normalized such that a loss implies a zero gross payoff.

[5] The marginal probability function for z_i = number of yellow or red cards awarded against the home team (i=1) and away team (i=2) is denoted $f_i(z_i)=\exp(-\lambda_i)\lambda_i^{z_i}/z_i!$ for z_i=0,1,2,... The joint distribution function is constructed by substituting the two univariate distribution functions, $F_i(z_i)$, into the Frank copula. The bivariate joint distribution function is: $G[F_1(z_1),F_2(z_2)]$ = $\frac{1}{\varphi}ln\left(1+\frac{\{exp[\varphi F_1(z_1)]-1\}\{exp[\varphi F_2(z_2)]-1\}}{exp(\varphi)-1}\right)$, where φ is an ancillary parameter. The zero-inflated joint probabilities are: $(1-\theta)P(z_1,z_2)+\theta D(z_1,z_2)$, where $P(z_1,z_2)$ is the bivariate joint probability function corresponding to $G[F_1(z_1),F_2(z_2)]$, $D(0,0)$=1 and $D(z_1,z_2)$=0 for $(z_1,z_2)\neq(0,0)$, and θ is an ancillary parameter. The zero-inflated adjustment allows the probabilities for the cell (z_1=0,z_2=0) to be larger than is suggested by the Poisson distribution: an empirical regularity that is evident in the current data.

[6] Alternative algorithms, based on different assumptions concerning the average performance of competing teams over their remaining fixtures, alter the classification of a small proportion of matches at the margins, but the implications for the estimation results are negligible.

[7] This model generates probabilities for home win, draw and away win outcomes, based solely on historical data that are available prior to the match in question. Full details are reported in Goddard (2005), and are not repeated here.

[8] The season dummies are $S_s = 1$ if the match is played in season s; 0 otherwise (s represents seasons 2002/03 to 2006/07 inclusive; 2001/02 is the reference category). The referee fixed effects are $R_r = 1$ if the match is officiated by referee r; 0 otherwise (r=1...106 represents referees who officiated at least 30 matches within the observation period; those referees who officiated fewer than 30 matches each form the reference category). The team fixed effects are constant over all home games or away games for each team.

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Table 1: Descriptive statistics, sample data

Number of fouls, *F*	Number of matches in which *F* fouls were awarded against: Home team	Away team	Number of yellow cards, *Y*	Number of matches in which *Y* yellow cards were awarded against: Home team	Away team	Number of red cards, *R*	Number of matches in which *R* red cards were awarded against: Home team	Away team
0-4	167	143	0	3535	2294	0	11353	10856
5-9	2762	2203	1	4172	3644	1	817	1263
10-14	5818	5561	2	2829	3287	2	43	92
15-19	2924	3464	3	1184	1905	3	3	4
20-24	503	778	4	389	754	4	0	1
25+	42	67	5+	107	332			
Total	12,216	12,216	Total	12,216	12,216	Total	12,216	12,216
Mean	12.4007	13.1212	Mean	1.2687	1.6957	Mean	0.0747	0.1198
St. dev	3.9759	4.1345	Variance	1.2834	1.6706	Variance	0.0776	0.1234

Table 2: Estimation results

Dependent variable → ↓ Independent variables	Home team: Fouls	Home team: Yellow cards	Home team: Red cards
HSIG	0.1278	0.0125	0.0758
	(0.85)	(0.34)	(0.50)
HPROB	-1.4023***	-0.7582***	-0.2855
	(-2.53)	(-5.81)	(-0.47)
UNCERT	8.0678***	0.3991	6.5548**
	(2.84)	(0.58)	(2.09)
Dependent variable → ↓ Independent variables	Away team: Fouls	Away team: Yellow cards	Away team: Red cards
ASIG	0.3419**	0.1674***	0.3985***
	(2.13)	(4.87)	(2.67)
HPROB	1.9253***	0.3105**	0.7873*
	(2.92)	(2.31)	(1.49)
UNCERT	12.4976***	1.0239**	4.8913**
	(4.27)	(1.72)	(2.04)

Notes

The fouls equations are estimated as Seemingly Unrelated Regressions (SUR). The yellow and red cards equations are estimated as a bivariate Poisson regression. Ancilliary parameters (allowing for interdependence between the home team and away team fouls or cards, and the zero-inflation parameter) are not reported.

Additional controls included in these regressions are individual effects for (i) soccer seasons, (ii) teams and (iii) referees. Coefficients are not reported.

*, **, *** denote coefficients significant at the 10%, 5% and 1% levels, respectively, one-tail tests.

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