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Arbitrage in a Basketball Economy

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I. INTRODUCTION

It is difficult to assess managerial performance in team production processes. Several recent papers use stock returns as a proxy for CEO performance [COUGHLIN and SCHMIDT, 1985; WARNER, WATTS and WRUCK, 1988; and WEISBACH, 1988]. However, this measure is clearly not a monotone transform of managerial effort. D'ANGELO [1988] shows that dissident groups use poor earnings to claim that current management should be replaced; she also shows that management manipulates subsequent earnings announcements during the proxy contest. In this paper we model team production literally, using data from the National Basketball Association (NBA) to create a basketball economy[1]. We derive a measure of one dimension of managerial (coaching) performance that is independent of the quality of inputs and show that variations in coaches' performance are significantly related to winning in a well-specified production function. We also show that employment of coaches is significantly affected by their ability to maximize our performance measure. In the NBA, coaching

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1. There is a growing literature that uses sports data to test economic theories [GOFF and TOLLISON, forthcoming]. The rationale for such an approach is that sports events provide a natural laboratory where a large number of competitive events take place under controlled conditions, which are in turn carefully and accurately described by reporters and sports statisticians. The problem of data contamination in sports is minimal because there are many interested observers of events who have clear incentives to correct false reporting. The key ideas in this approach are two-fold: a) to show how economic principles apply to the play of sporting events, and b) to test more general hypotheses derived from economic models using clean data from sports competition. On the concept of a basketball economy, see MCCORMICK and TOLLISON [1984, 1986].

ability does matter, and the managerial labor market recognizes ability, providing incentives for coaches as FAMA [1980] has argued[2].

We concentrate on a single dimension of coaching productive efficiency — the allocation of shots across players on a team — by deriving a simple point-maximizing rule for shot allocation and constructing an empirical measure of coaches' success in enforcing this rule. We show that managers who allocate shots better increase team victories and improve their own job security[3].

This is a testable theory of managerial behavior. The implication is that other things equal, the higher the correlation across players of shots attempted with field-goal shooting percentage, the more wins a team will have. Moreover, there is ample data on the NBA to test this hypothesis while controlling for a rich set of *ceteris paribus* conditions[4].

2. FAMA uses a sports metaphor to explain the importance of the managerial labor market — 'The manager of a firm, like the coach of any team, may not suffer any immediate gain or loss in current wages from the current performance of his team, but the success or failure of the team impacts his future wages, and this gives the manager a stake in the success of the team' [FAMA, 1980, p. 292].

3. This paper is related to recent work by CLEMENT and MC CORMICK [1989a, 1989b]. First these authors [1989a] estimate an equation predicting playing time as a function of player statistics using data from college basketball teams. They show that the better their model replicates individual coaches' actions, the better that team performs. An interesting result in this paper is that only half the variation in playing time can be explained by player statistics. Unmeasured factors are important; this importance is what we stress in this paper. Second CLEMENT and MC CORMICK [1989b] outline and test a theory of arbitrage between 2- and 3-point shots in the NBA. They find that better coaches are better at equating the expected value of 2- and 3-point shots. The argument in this paper is a more general version of theirs, in which the coach is modelled as attempting to equalize the expected value of all shots taken. Operationally, this implies that shots will be distributed in proportion to field-goal shooting percentages of players.

4. A couple of caveats are in order at the outset. First, the shot-allocation problem that the coach faces is complex from an *ex ante* perspective. Field-goal shooting percentages will vary by player by game, and a better coach will observe these changes and enforce a different shot-allocation scheme as a result. Testing for the game-by-game ability of coaches in this sense is not possible. Available data come in an *ex post*, season summary form, so that the best one is able to do is to see how well the coach made his shot-allocation decisions based on season-long averages. Second, the shot-allocation problem represents a method with which to evaluate the offensive coordination ability of a coach. This is only a partial measure of the marginal product of a coach. Coaches must also organize and enforce defensive pressure, rebounding, yelling at officials, and the judicious use of fouls, among many other things. This paper thus does not purport to measure the marginal product of a managerial input completely; it seeks to illustrate the process of in-firm arbitrage on the offensive end of the basketball court.

II. A SIMPLE MODEL

As outlined above, the problem to be considered can be analyzed in agency terms. The owner(s) of the team seeks to maximize franchise profits[5]. The coach seeks to maximize his income which is postulated to be a function of team wins. (Attendance and profits are related to wins.) Players seek to maximize their income which is assumed to be a function of their personal performance statistics. An agency problem arises because players have an incentive to add to their personal statistics at the expense of team cooperation. The ability of a player to cooperate with team strategy in order to produce wins is assumed to be insider information with respect to a given team and coach and hence is not marketable by the player outside his given team.

Consider the issue of who gets to take shots. A point-maximizing rule for the team would distribute shots so that at the margin field-goal percentage is equalized across players. Nonetheless, players want to maximize their personal performance statistics since by assumption these data determine their opportunity wages. The coach wants to win and hence must use incentives, such as playing time (see CLEMENT and MC CORMICK [1989a]), and monitoring, such as calling plays and yelling, to force his players/agents to act for the team good as much as possible. The more efficiently shots are allocated given the differential skills of players, the more points will be scored and the more games will be won, all else equal. Obviously, this agency problem applies to all aspects of a player's performance, but shots are one of the most clearly measurable aspects of player activities as opposed, for example, to passing, screening, and defensive pressure.

A typical agency problem involves agents (along with nature) producing an outcome valued by the principal, but agent effort produces disutility and is unobservable, so the principal must design a contract to make the incentives of agents compatible with his goals. In basketball team production some types of agent effort are observable and verifiable by outsiders. It is assumed that agents maximize their market value by concentrating effort on these verifiable indicators (for example, steals, rebounds, points per game). However, in order to maximize wins or team performance, agent cooperation is required, and this type of effort is not verifiable by outsiders and will not be strongly related to

5. Some have questioned whether the owners of professional sports franchises are, in fact, profit maximizers. See, for example, DEMSETZ and LEHN [1985], who argue that ownership is concentrated in such cases because of the amentity production potential of owning a sports team. If, however, amentity production is related to wins, the argument in the text is equally applicable to this setting.

agents' market value. Agent cooperation is where shirking may occur within this framework. Thus, sports owners hire monitors (coaches) to regulate team production. The monitor can observe the extent of cooperation, but this information cannot be credibly communicated to outsiders. Indeed, the coach has no incentive to be truthful to his owner or any other party interested in the cooperative behavior of the players/agents[6]. Coaching success involves maximizing wins for a given talent pool, basically, enforcing efficient team production[7]. The argument can be given a simple mathematical representation. Consider a point production function for a team of the form:

$$P\left(S_i \dots S_n\right) = \sum_{i=1}^{n} a_i \log S_i \qquad (1)$$

where S_i is shots by player i and a_i is the relative skill level of player i. The a_i are different across players on a team and are given a functional form such that the average and marginal shooting products of players will differ but all will decline at the same rate.

The coach's problem is to maximize equation (1) subject to a total shot constraint, or

$$\sum_{i=1}^{n} S_i = C \qquad (2)$$

where C is a total shot constraint for a game. This constraint can be pictured as the result of the interplay between playing time (48 minutes) and such factors as the quality of the opposition's defense. Ex ante, going into any game, a coach will have a rational expectation of how many shots will be possible. In other words, the coach will seek to maximize

$$\Theta = \sum_{i=1}^{n} a_i \log S_i + \lambda \left(C - \sum_{i=1}^{n} S_i \right). \qquad (3)$$

6. The coach may, for example, wish to blame (falsely) losses on shirking by players.

7. Players are somewhat like professors who must allocate time between teaching and research. Individual professor incentives are to produce identifiable outputs such as research at the expense of teaching performance because their opportunity wage is determined by research and not teaching performance.

The equilibrium condition in the coach's problem is simply

$$S_i^* = \frac{a_i}{\sum_{i=1}^{n} a_i} C \tag{4}$$

or

$$S_i^*/C = \frac{a_i}{\sum_{i=1}^{n} a_i} .$$

In other words, the coach's derived demand for the proportion of team shots taken by a given player is a function of the player's relative skill. Given the assumption of declining marginal shooting products, the best player will not take all the shots; shots will be distributed among players so that field-goal shooting percentages are equalized across players.

Consider this process in the actual play of a game. When his team is on offense, each coach will have a scheme of attack. This scheme will vary with the opponent's defensive strategy and the distribution of player skills for each team. In this setting one player will not take all the shots. Should a good shooter get hot, defensive alignments will be shifted to increase the difficulty of his shots. At some point, the good shooter will be directed by the coach to look for the open man rather than for his shot. In such a way shifting defensive pressure will cause marginal shooting products to decline in the course of a game.

We can test this theory using NBA data. Relative skill at shooting can be measured by player field-goal shooting percentages for a season. The efficient allocation of shots can be measured by the rank correlation of field goals attempted with field-goal shooting percentages across players by team. The higher this correlation, the more games teams will win, all else the same. And if economic returns for coaches and owners flow from wins, rational shot allocation should also lead to other observable consequences such as longer tenure and higher pay for better shot allocators.

III. EMPIRICAL MODEL AND RESULTS

Using annual issues of the NBA *GUIDE*, data were collected with respect to the following statistics for all NBA teams for the five seasons preceding the introduction of the 3-point shot (1974-75 to 1978-79): field-goal shooting percentage, free-throw shooting percentage, rebounds, assists, fouls, steals, turnover, and blocked shots, These data come in two forms, both in terms of how each performed against opponents and how opponents performed against each team over the same categories. There are therefore 16 total control variables. There were 18 NBA teams in the 1974-75 and 1975-76 seasons, and 22 teams for the other three seasons in the data[8]. In addition and also using the NBA *GUIDES*, individual player data for each team were collected for field-goal shooting percentage and number of field goals attempted. These data enable us to operationalize the measure of coaching efficiency expressed as the correlation between field-goal attempts and field-goal shooting percentage by team[9].

The basic model estimated is therefore:

WINS = f(SCOR, OFGP, DFGP, OTR, DTR, OPF, DPF, OS, DS, OBS, DBS, OAST, DAST, OFTP, DFTP, OTRN, DTRN)

where
WINS = team victories (all data cover five seasons);
SCOR = the Spearman rank correlation between field-goal shooting percentage and shots attempted by player by team (this is our measure of coaching efficiency); (+)
OFGP = team field-goal shooting percentage; (+)
DFGP = opponents' field-goal shooting percentage; (-)
OTR = team total rebounds; (+)
DTR = opponents' total rebounds; (-)
OPF = team personal fouls; (-)
DFP = opponents' personal fouls; (+)
OS = team steals; (+)
DS = opponents' steals; (-)
OBS = team blocked shots; (+)
DBS = opponents' blocked shots; (-)

8. The American Basketball Association (ABA) and the NBA merged prior to the 1976-77 season, and four ABA teams entered the NBA (Indiana, San Antonio, Denver, and New Jersey). The basic model of basketball production followed in this section is derived from ZAK, HUANG and SIEGFRIED [1979] and SCOTT, LONG and SOMPPI [1985].

9. The sample is confined to players who took at least 250 shots in a season (about 3 shots per game).

OAST = team assists; (+)
DAST = opponents' assists; (-)
OFTP = team free-throw shooting percentage; (+)
DFTP = opponents' free-throw shooting percentage; (-)
OTRN = team turnovers; and (-)
DTRN = opponents' turnovers. (+)

The 17-variable model using Spearman rank correlations between player field-goal shooting percentage and field goals attempted is employed to explain team victories in *Table 1*, equation (1). Identical regressions using Pearson correlations as the measure of coaching efficiency yield similar results and are available on request from the authors[10]. Equation (1) in *Table 1* has an R^2 of about .85, and all significant variables have the expected sign, except for offensive assists which are negative and significant. Field-goal shooting percentage, rebounds, and turnovers are the most significant explanatory variables. Most importantly, the measure of coaching efficiency (SCOR) is positive and significant at the 0.01 level.

10. No *a priori* predictions were made about which of the 16 performance statistics would be important, so all of them were included at this stage. Tests were conducted about whether the performance statistics could be entered on a 'net' basis (net field-goal percentage = team field-goal percentage - opponents' field-goal percentage). This restriction was rejected by the data at the 0.05 level. In computing these correlations, we took players traded during the year and projected their statistics with their new teams over a full season. We ran the regressions on the raw correlations as well, and the SCOR and Pearson correlation variables retain their reported significance levels, but the coefficients are smaller.

Table 1

Season Statistics, Coaching Efficiency, and Wins in the NBA: 1974 - 1975 — 1978 - 1979

Variable	Equation 1		Equation 2	
Constant	66.6	(1.46)	82.57	(2.02)
SCOR	2.70	(3.00)	2.62	(2.78)
OFGP	401.51	(8.13)	431.59	(9.65)
DFGP	-346.18	(7.46)	-364.03	(12.76)
OTR	0.0233	(6.86)	0.0230	(7.47)
DTR	-0.0187	(6.67)	-0.0181	(7.79)
OPF	-0.0153	(5.05)	-0.0159	(5.22)
DPF	0.0110	(2.72)	0.0102	(2.68)
OS	0.0045	(0.69)		
DS	-0.0213	(2.91)	-0.0252	(3.70)
OBS	0.0064	(1.10)		
DBS	-0.0069	(0.83)		
OAST	-0.0087	(2.55)	-0.0081	(2.41)
DAST	0.0006	(0.18)		
OTFP	22.84	(1.59)		
DFTP	-94.43	(3.45)	-99.41	(3.68)
OTRN	-0.0211	(3.97)	-0.0191	(4.07)
DTRN	0.0348	(5.16)	0.0377	(9.76)
F:	27.68		39.76	
R^2	0.849		0.843	

Numbers in parenthesis are t-statistics, calculated using WHITE's heteroskedastic-consistent covariance matrix. N = 102.

The coefficient on the rank correlation variable in equation (1) suggests that a 1 standard deviation increase in coaching efficiency produces about 1.00 more wins per season. The difference between the worst and best coaching performances in the data computes to 4.3 more wins. To put these results in perspective, consider that the following are also equivalent to producing 1.0 more wins per season: 43 more rebounds, 47 fewer turnovers, and a reduction in opponents' field-goal shooting percentage of 0.3 percentage points. Admittedly, the effect of coaching as measured in this test is not large, but as stressed previously, only one dimension of coaching ability is picked up in this test. Defensive coaching ability, for example, is not measured directly. Moreover, the higher the correlation statistic is, the higher the team field-goal shooting percentage is, which has an independent effect on wins that is quite important[11]. Finally, in 7 of the 20 divisional races in the data, the second place team finished 3 games or less behind the winner (finishing order is related to things like home-court advantage in the playoffs).

The results in equation (1) are robust. Using a backward elimination procedure to pare down the model, the weakest variable was eliminated, and the model was reestimated until all the remaining variables were 'significant' at the 0.10 level. This process produced the results in equation (2) in *Table 1*, where free-throw shooting percentage, steals, opponents' assists, and both shot-blocking variables were eliminated. In this regression, along with each of the 4 (unreported) intermediate regressions that were estimated, the coaching variable was significant at the 0.01 level and of the same general magnitude as in *Table 1*. While classical hypothesis testing is invalid in this type of data mining, the exercise demonstrates that the basic result is not an artifact of an idiosyncratic specification.

IV. COACHING EFFICIENCY AND TURNOVER

Our measure of offensive coaching efficiency has been shown to be significantly related to victories in the NBA. We now consider whether this measure of coaches' ability has any effect on their tenure of employment. The authors will provide, on request, a table which lists each coach in our sample along with his efficiency rating (SCOR) and wins. The most striking feature in this data is the amount of coaching turnover. The *NBA Guide* does not give the reason for a coaching change; we do not know whether a coach was fired, resigned, retired, or took a new coaching job. However, we can use this data to provide some simple evidence on the effect of coaching performance on tenure.

First, there are six coaches who coached the same team every year of the sample. They are AL ATTLES, BILL FITCH, BOB LEONARD, KEVIN LOUGHERY,

11. Any reallocation of shots that raises SCOR automatically raises a team's shooting percentage. Statistically, in our sample a one standard devation increase in SCOR raises shooting percentage by .41 percentage points, which according to the coefficients in *Table 1* implies an additional effect of 1.8 wins.

JOHN MACLEOD, and DOUG MOE. All other coaches suffered a job loss at some point in the sample. The average SCOR for these full-tenure coaches is .358, which is almost twice the average of all other coaches (.196). The coaches who held the same job the longest were significantly (t-statistic = 2.05) better shot allocators than their colleagues. Interestingly, there is no significant difference in average wins between the full-tenure coaches and the rest of the league. These results are given in panel A of *Table 2*.

Second, there are five cases where a coaching change was made during the season, and there was a single coach in the following year[12]. These are Atlanta, 1975, Kansas City, 1977, Milwaukee, 1976, New Orleans, 1976, and Philadelphia, 1977. Here, we compare the performance of the departing coach in his last full season with that of the first full year of the coach who followed. The average SCOR of the 5 mid-season departers is -.138, while their replacements averaged .243 in their first full years. This difference is significant at the 0.10 level. The difference between the replaced coaches and the rest of the league is significant at the 0.05 level. Again, there is no significant difference in average wins between the replaced coach and his replacement or the league average. These five cases are the most likely firings in the data, and it appears clear that coaches who performed poorly as shot allocators were replaced by better allocators. These results appear in panel B of *Table 2*. While there is a lot of coaching turnover that we can say nothing about, at the extremes SCOR varies dramatically. Full tenure coaches are far above average, and coaches replaced during the season are far below average.

Two tentative implications emerge from these results. First, coaching turnover does not appear to be capricious. It is related to an observable ability of a coach and not to some gross performance statistic such as wins. Coaches appear to be evaluated by their measurable performance with a given pool of player talent. Second, as postulated in the theory of team production [ALCHIAN and DEMSETZ, 1972], the monitor of a team production process does indeed have a positive marginal product.

12. This situation also occurred with the Detroit Pistons in both 1975 and 1977, but the replacement coach in the 1976 season was the fired coach in the 1977 season. Rather than double-counting him in both categories, the observations were dropped. The Pistons employed four different coaches in our five-season sample.

Table 2

SCOR and Coaching Turnover

A: Full Tenure Coaches vs. the Rest of the League

Coach	Team	Average SCOR	Average WINS
John Mac Leod	Suns	.604	41.40
Doug Moe	Spurs	.558	48.00
Kevin Loughery	Nets	.397	27.67
Bill Fitch	Cavaliers	.413	41.00
Bob Leonard	Pacers	.320	35.00
Al Attles	Warriors	-.144	46.80
Goup Average		.358	39.98
Rest of League		.196	41.08

t-statistic on difference of average SCOR: 2.05**
t-statistic on difference of average WINS: 0.63

** indicates significance at .05 level

B: Coaches Replaced During the Season vs. the Rest of the League and Their Replacements

Team	Year	Replaced Coach SCOR/WINS (Last Full Year)	Coach Next Season SCOR/WINS
Hawks	1975	Fitzsimmons -.479/31	Brown .354/31
Jazz	1976	von Breda Kolff -.364/38	Baylor -.042/39
Bucks	1976	Costello .429/38	Nelson .442/44
76ers	1977	Shue -.393/59	Cunningham -.200/47
Kings	1977	Johnson .115/40	Fitzsimmons .661/48
Group Average		-.138/39.4	.234/41.80
Rest of League Average (includes the new coaches above)			.248/41.08
t-statistic on difference in average SCOR between replaced coaches and their successors:			1.77*
t-statistic on difference in average WINS between replaced coaches and rest of league:			2.40**
t-statistic on difference in average WINS between replaced coaches and their successors:			0.44
t-statistic on difference in average WINS between replaced coaches and rest of league:			0.43

** indicates significance at .05 level, * at 0.10 level

V. CONCLUSION

The general economic problem addressed in this paper relates to the nature of the management of team production processes. The managerial input is not necessary in areas of production where worker output can be counted and evaluated by the outside labor market. Workers have a direct incentive to maximize individual performance statistics in this setting. The managerial input is required to enforce team cooperation where individual performance incentives and firm incentives diverge. This is the way basketball team production works, and indeed is an element of most team production processes. Modern large corporations, for example, are organized along divisional lines, where divisions may compete as profit centers. This setting is analogous to the basketball problem. Divisional sales and profits can be measured, and individual division managers will attempt to maximize such indicators. Yet firm profits may rise if resources are allocated away from a profitable division to an even more profitable division. Manager cooperation in the division losing resources is not marketable; hence, the management of divisional competition is very much like a larger scale problem of managing basketball team production. Beyond such considerations, however, this paper derives a 'pure' measure of managerial input into a team production process, and shows that it matters, in the way the literature on the market for managers says it should.

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SUMMARY

This paper addresses the role of the manager in a team production setting. The coach of a basketball team faces a team production arbitrage problem. He must monitor and enforce a process that distributes shots among players such that the expectation that each shot taken will be made is maximized. This paper articulates an agency theory of this arbitrage process, and tests it with data on the National Basketball Association.

ZUSAMMENFASSUNG

Der Artikel behandelt die Rolle des Managers bei der Erstellung eines Teams. Der Trainer eines Basketballteams sieht sich bei der Teamproduktion mit einem Arbitrage-Problem konfrontiert. Er muss einen Prozess überwachen und forcieren, mittels dem die Schüsse zwischen den Spielern so verteilt werden, dass die Erwartung, dass jeder ausgeführte Schuss ein Treffer ist, maximiert wird. Der Artikel formuliert eine Agency-Theorie dieses Arbitrage-Prozesses und testet diese mit Daten der National Basketball Association.

RÉSUMÉ

Cet article aborde le rôle du responsable dans la production d'une équipe. L'entraîneur d'une équipe de basket est confronté à un problème d'arbitrage dans la production de l'équipe. Il doit concevoir et faire appliquer le processus qui répartit les tirs entre les joueurs afin de maximiser l'espérance de réalisation des tirs prévus. L'article développe une théorie de l'agencement de ce processus d'arbitrage et la teste avec des donneés fournies par la 'National Basketball Association'.