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Informed Traders and Price Variations in the Betting Market for Professional Basketball Games

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ABSTRACT

This paper examines betting line changes from the opening to the closing of the point spread betting market on National Basketball Association games for evidence of informed trader betting. We show that within-betting period line changes significantly improve the accuracy of betting lines as forecasts of game outcomes. We examine individual line change magnitudes and show that these are directly and proportionately related to biases in opening lines. Further, line changes are of sufficient magnitude to remove these biases by the close of betting. We interpret these results as evidence that informed traders are influential in this market.

DO DAY-TO-DAY AND WITHIN-DAY changes in asset prices reflect the incorporation of information into price? A number of recent market microstructure papers have cast doubt on the incorporation of information explanation. For example, studies of day-to-day price changes by French and Roll (1986), Roll (1988), and Cutler, Poterba, and Summers (1989) show that market volatility is much larger over periods when the market is open than over comparable periods when the market is closed, and that external news is not responsible for the majority of large daily stock price changes. The implication of this research is either that the arrival of private information causes price volatility or that trading itself introduces noise into prices. The within-day price change studies by Amihud and Mendelson (1987) and Stoll and Whaley (1990) demonstrate that prices formed at the opening of trading are more volatile than prices determined at other times of the day. These authors suggest that trading mechanisms used at the start of trading may be responsible for noisier opening prices.

Efforts to validate the incorporation of information explanation have proceeded apace. At the theoretical level, for example, Romer (1993) develops a model allowing for rational changes in the market's assessment of funda-

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mentals, and hence, rational price movements, in the absence of the arrival of outside news. There are also numerous empirical studies. For example, Ederington and Lee (1993), building on the work of Harvey and Huang (1991), show that scheduled macroeconomic news announcements are responsible for most of the observed time-of-day and day-of-the-week volatility patterns in interest rate and foreign exchange futures markets. Gerety and Mulherin (1994), using forty years of hourly price index data from the New York Stock Exchange, find that transitory price volatility declines steadily over the trading day. This price volatility pattern is consistent with the hypothesis that trading aids price formation rather than the alternative arguments that trading mechanisms add to price volatility at the opening or that price changes are simply noise.

An impediment for all empirical research into asset price changes is the lack of an endpoint at which an objective fundamental value can be observed and compared with actual prices. As a result, neither the price formation, trading mechanism, nor noise trading hypotheses can be directly tested in conventional financial markets. A number of authors have pointed out that point spread betting markets offer unique opportunities for directly testing hypotheses about the operation of financial markets (recent examples include Gandar et al. (1988), Camerer (1989), Brown and Sauer (1993a, 1993b), and Dare and MacDonald (1996)). In betting markets, fundamental values in the form of differences in the points scored by the two teams are revealed as games are played; market forecasts of these point differences (prices) are represented by point spread betting lines.

Most betting market studies have focused on a static relationship between value and price and have largely ignored price variations. The Brown and Sauer (1993b) study examining the point spread betting market on National Basketball Association (NBA) games is an interesting exception. These authors demonstrate that game-to-game variations in point spread betting lines reflect fundamental information, and that forecast errors of their model (differences between actual betting lines and their model's forecasts of these lines) are directly and proportionately related to actual game outcomes. Brown and Sauer interpret this result as a strong indication that the unexplained game-to-game betting line variations, rather than being noise, represent fundamental information. To extend our knowledge of price formation, we examine changes in betting line from the open-to-the-close of wagering on NBA games to determine whether bettors are incorporating fundamental information into price or if these movements are noise.

We begin by showing that line changes occur for nearly 80 percent of NBA games in our sample and that large line changes are frequent: nearly one-third are greater than a point in magnitude. We show that these line changes significantly improve the accuracy of lines as forecasts of actual game outcomes. More importantly, the evidence suggests that there are biases in opening lines and that trading appears to remove these biases by the close of the book. In essence, we show that price changes in this elementary market cause prices to more accurately reflect fundamental values.

The following section provides background information on the NBA point spread betting market and the frequency and magnitude of line changes in it. In Section II the relative forecast accuracy of opening and closing lines is examined. Section III develops tests for individual line change magnitudes and presents the results of these tests for our sample of NBA games. Section IV compares and contrasts our findings with other studies of point spread betting markets. Section V concludes.

I. Line Changes in the NBA Betting Market

A. Overview of NBA Point Spread Betting Market

The betting market on NBA games begins with the posting of opening lines at 8:00 a.m. Pacific Standard Time (PST) in the Stardust Race and Sports Book in Las Vegas. Almost all other books in Las Vegas (and elsewhere) open shortly thereafter. The market for a game closes several hours later at the game tip-off (somewhere between eight and eleven hours later for weekday games, and between one and eleven hours later for weekend games).

Opening lines represent the bookmaker's evaluation of both the likely game outcomes (point spreads) and the bookmaker's perception of the betting market's evaluation of these outcomes.[1] They are designed to attract equal dollar betting on each side of the proposition. If balanced betting occurs at the opening line, the book secures a riskless profit from the "eleven-for-ten" trading rule. If unbalanced betting occurs, the book may adjust lines in an attempt to equalize the monies bet on each team and thereby avoid exposure to unnecessary risk. In this way, closing betting lines reflect the (dollar-weighted) market expectation of game outcomes. They are thus both market equilibrium clearing prices and market forecasts of actual game outcomes.[2]

Descriptive statistics for the data analyzed in this paper are given in Table I. These data are opening and closing betting lines and game outcomes for all 9,940 games played over the nine NBA seasons, 1985–86 through 1993–94.[3] The betting lines are the actual opening and closing

[1] Although individual bookmakers post their own opening lines, almost all (including the Stardust) base these on betting lines developed by the principal oddsmaker in Las Vegas, Michael "Roxy" Roxborough of Las Vegas Sports Consultants.

[2] Rationality requires that the odds of winning be equal for a bet on either team. For this to happen, the market should clear at the median, and not the mean, of the distribution. We examine the distribution of actual score differentials and are unable to reject the null hypothesis of symmetry for all seasons individually and collectively. As well, as noted in Gandar et al. (1988), it seems reasonable to assume there is no systematic risk in point spread outcomes. Thus, we ignore the problem of adjusting for risk here.

[3] There were actually 10,030 (regular season and playoff) games played over these nine NBA seasons. However, for 90 games either an opening line or a closing line or both was not posted, leaving 9,940 observations in our sample. The principal reason for not posting a line on a game is uncertainty over the participation (usually because of injury) of a key player.

lines for the Stardust Race and Sports Book obtained from *Computer Sports World*.[4] Mean actual game scores (AS) ordered on a home team points scored (HPS) less visiting team points scored (VPS) basis (that is, AS = HPS − VPS) show the actual home court advantage (for example, AS averages 4.67 points for the 1985–86 season).[5] Average opening and closing betting lines (OL and CL, respectively) ordered on the same home team basis measure the home court advantage expected by the bookmaker and the betting market (for example, CL averages nearly 4.5 points in 1985–86). Although these mean forecasts of game outcomes largely coincide with actual game outcomes, standard deviations of the latter relative to the former are much higher—there is much more unpredictability in actual game outcomes.

B. Frequency and Magnitude of Line Changes

The frequency and magnitude of actual line changes (defined as $\Delta L = CL - OL$) over the nine NBA seasons are shown in Table II. Nearly 80 percent of all games have nonzero line changes. A sizeable proportion of these line changes are small; for example, 40 percent of line changes from opening to closing are of one-half point magnitude.[6] However, there are many instances where the magnitude of the line change is considerable. For example, there are 2,414 one-point line changes (31 percent of all line change games), and 2,305 line changes greater than one point (29 percent of all line change games). The largest changes are two instances of an eleven-point swing in betting lines. It is evident that line changes are an important bookmaker activity.

[4] Most previous studies of point spread betting markets have used media lines or some composite of Las Vegas betting lines—both introduce the possibility of measurement error. Media lines are reported in morning papers for that day's games and represent, at best, an estimate of opening betting lines posted several hours later. Oorlog (1995), for example, uses lines from the *Kansas City Star*. Composite lines are frequently intermediate lines representing neither opening nor closing lines. Use of composite betting lines are numerous: Gandar et al. (1988), Russo, Gandar, and Zuber (1989), Camerer (1989), and Brown and Sauer (1993a, 1993b) all use such lines. A good example of such lines is the use by Brown and Sauer of a line recorded at 2 p.m. PST, six hours after the opening of Las Vegas books, but roughly 2.5 hours before the typical weekday game tip-off in the Eastern time zone. Even though Brown and Sauer use a composite line, a casual comparison of the mean and standard deviations for the lines they use (variable PS, Table I, p. 1196, Brown and Sauer (1993b)) and actual closing lines (our variable CL, Table II) for comparable periods finds these variables very similar.

[5] Prior studies of point spread betting markets have ordered the differencing on both this home team basis and on a favorite team basis. We perform all the tests reported in the paper using favorite team differencing and find virtually identical results to the home team differencing results reported here. The favorite team differencing results are available from the authors upon request.

[6] It is important to remember that even changes as small as this can have economic impact. Suppose, for example, that the home team opens as a 4 point favorite and closes as a 4.5 point favorite. If the home team wins the game by exactly 4 points, all bets on the home team at the closing line lose and bets at the opening line are refunded (they are "pushes").

Table I

Summary Statistics: Actual Game Scores and Betting Lines 1985–1986 to 1993–94 NBA Seasons

The betting lines are actual opening lines (OL) and closing lines (CL) from the Stardust Race and Sports Book obtained from *Computer Sports World*. *N* is the number of games in each season where both opening and closing lines were offered. Actual game scores (AS) are ordered on a home team less visiting team basis, i.e., AS = HPS − VPS, where HPS and VPS are the points scored by the home and visiting teams respectively. The opening and closing betting lines are also from the perspective of the home team. The columns of mean statistics represent the actual home team advantage (AS Mean), the bookmaker estimate of the advantage (OL Mean), and the final closing line market-determined estimate of the advantage (CL Mean). Standard deviations for the samples are in parentheses.

Season	*N*	AS Mean (std. dev.)	OL Mean (std. dev.)	CL Mean (std. dev.)
1985–86	1006	4.67	4.34	4.49
		(12.36)	(5.28)	(5.65)
1986–87	1013	5.19	4.79	4.91
		(13.13)	(5.65)	(6.06)
1987–88	1021	5.78	5.22	5.29
		(12.35)	(5.83)	(6.04)
1988–89	1087	5.41	5.38	5.35
		(13.47)	(6.92)	(7.01)
1989–90	1179	5.12	5.17	5.17
		(12.84)	(6.36)	(6.59)
1990–91	1174	4.59	4.85	4.86
		(13.19)	(6.68)	(6.91)
1991–92	1180	4.59	4.92	4.80
		(13.20)	(6.30)	(6.51)
1992–93	1172	4.11	4.35	4.24
		(13.34)	(6.64)	(6.78)
1993–94	1108	4.03	4.18	4.17
		(13.28)	(6.49)	(6.68)
All seasons	9940	4.81	4.80	4.81
		(13.06)	(6.29)	(6.51)

C. Bookmaker Line Change Rationales[7]

Bookmakers frequently encounter betting imbalances on posted games.[8] These imbalances may cause bookmakers to change lines in an attempt to attract more betting on the less popular proposition and, thereby, balance the dollars bet on both sides by the close of betting. There are a number of reasons for betting to be unbalanced at opening lines and hence, for lines to change. These include the release of new information after betting begins,

[7] Further details are given in Gandar et al. (1988).

[8] This statement is based on the authors' conversations with Lenny Del Genio, manager of Bally's Race and Sports Book, and Bob Gregorka, manager of The Desert Inn Race and Sports Book. For a basic primer on practical sports book management, see Rhoden and Roxborough (1988).

Table II

Distribution of Betting Line Changes (ΔL)

Betting line change is defined as the closing line minus the opening line: $\Delta L = CL - OL$. The absolute values of the changes, $|\Delta L|$, are used for descriptive purposes. Line changes greater than four and less than negative four are grouped to conserve space and statistical power. N is the number of games at each $|\Delta L|$ value. For the 7904 games in the sample where $|\Delta L| \neq 0$, the mean value of $|\Delta L|$ is 1.08 with a standard deviation of 0.80.

$\lvert\Delta L\rvert$	N	Cumulative Percent
0.0	2036	20.48
0.5	3185	52.52
1.0	2414	76.81
1.5	1141	88.29
2.0	658	94.91
2.5	260	97.52
3.0	139	98.92
3.5	60	99.52
≥4.0	47	100.00
	9940	

the randomness of order flow, and prediction errors on the part of the aggregate betting public and/or bookmakers.

The first two explanations, information release and order flow, are unable to account for all line changes in this market. The release of new information may explain some line changes in the betting market on National Football League (NFL) games where there is a period of nearly one week between the opening and closing of a book on a game,[9] but we believe that the brief trading period for NBA betting largely precludes this explanation of line changes. Again, although it is possible that small line changes (for example, half-point changes) reflect the randomness of order flow in this market, this is an unlikely explanation for the considerable number of larger line changes. A line movement of, say, two points, requires continued betting on one team even as that team's chances of beating the line (and thus of bettors winning their bets) declines. This suggests that such line changes reflect an aggregate betting sentiment on the likely game outcome very different from the bookmaker's opening line, rather than a flood of orders on one team at the close of betting.

Line changes could arise from irrationality on the part of the aggregate betting public. If bookmakers set unbiased opening lines, unbalanced betting by noise traders could cause lines to move, thereby creating biases in closing lines. Alternatively, if bookmakers anticipate predictable irrationality in public betting, they may purposely bias opening lines in order to get balanced

[9] Even here the release of new information is not very important: Gandar et al. (1988) report that no more than 5 percent of all line movements in the NFL betting market stem from this source (see Gander et al.'s footnote 5, p. 997).

betting.[10] Because any consistent bias would be detectable and exploitable by informed traders, the strategy of intentionally setting biased opening lines works only if noise traders dominate (in aggregate dollars bet). In this scenario of irrational public betting, opening lines may be biased and line movements are noise.

Opening lines may not always fully utilize available public information. Any such line-setting errors create profitable betting opportunities for informed traders. Alternatively, some bettors may have access to information unavailable to bookmakers setting opening lines. In either case, the resulting betting imbalances would be expected to win against opening lines more than half the time. To protect their profits in the face of such informed trading, bookmakers will readily change lines. With line changes reflecting the activity of informed traders, closing lines should be more accurate forecasts of game outcomes.

II. Relative Forecast Accuracy of Opening and Closing Lines

In this section we begin the examination of line changes in this market by testing the relative forecast accuracy of opening and closing lines. If betting line changes from the opening to the closing are noise, there should be either no difference between the relative accuracy of opening and closing lines as forecasts of actual game outcomes, or, alternatively, closing lines may be inferior to opening lines as forecasts of these outcomes. However, if betting line changes result from informed betting, closing lines may be superior forecasts.

Summary statistics measuring the relative forecast accuracy of opening and closing lines are presented in Table III. The table reports both mean absolute forecast errors (MAFE) and mean square forecast errors (MSFE). For each season and for all seasons combined the closing line mean absolute forecast errors (MAFEC) either are approximately equal to or marginally smaller than opening line mean absolute forecast errors (MAFEO). Closing line mean square forecast errors (MSFEC) are smaller than opening line mean square forecast errors (MSFEO) for eight of the nine seasons. The exception is the 1992–93 season. For all seasons combined MSFEC is smaller than MSFEO by about two points.

To investigate the statistical difference between the relative predictive abilities of the two forecasts we use the procedure developed by Ashley, Granger, and Schmalensee (1980), the AGS test, which involves estimating the equation

$$(\text{FEO} - \text{FEC}) = \alpha + \beta[(\text{FEO} + \text{FEC}) - (\text{MFEO} + \text{MFEC})] + \mu, \qquad (1)$$

[10] Dare and MacDonald (1996) suggest this point based on their evidence of an apparent inefficiency in the wagering on Superbowl games. The "hot hand" phenomenon explored by Camerer (1989) and Brown and Sauer (1993a) may be another example of irrational betting that bookmakers take into account in setting opening lines.

Table III

Measures of Relative Forecast Accuracy of Opening and Closing Lines

Mean absolute and mean square forecast errors of the opening and closing lines along with the Ashley, Granger, and Schmalensee (AGS) test examining for the relative forecast accuracy of the two lines are given here. N is the number of games where the line changed in a season (CL $\neq$ OL). MAFEO is the mean absolute value of the opening line forecast error (Σ|actual score − opening line|)/N and MAFEC is the same statistic calculated using closing lines rather than opening lines. Mean square forecast errors for the opening and closing lines (MSFEO and MSFEC, respectively) are calculated similarly to MAFEO and MAFEC but squaring the errors rather than taking absolutes. Intercept and slope coefficient estimates ($\hat{\alpha}$ and $\hat{\beta}$), and associated t-statistics and p-values are for the AGS null hypothesis that the difference in the mean square errors between the forecasts is zero. This null requires that the intercept and slope terms are jointly zero. The alternative, that the mean square error from the first forecast (MSFEO) is larger than that for the second forecast (MSFEC), requires that both coefficients be nonnegative and at least one coefficient be strictly positive.

		Mean Absolute Forecast Errors		Mean Square Forecast Errors		AGS Test Equation Regression Results	
Season	N	MAFEO	MAFEC	MSFEO	MSFEC	$\hat{\alpha}$ (p-value)	$\hat{\beta}$ (p-value)
1985–86	785	8.85	8.76	132.14	131.58	0.915 (0.001)	0.001 (0.646)
1986–87	806	9.16	9.06	138.52	136.42	0.156 (0.001)	0.004 (0.053)
1987–88	813	8.72	8.68	122.98	120.59	0.085 (0.062)	0.005 (0.020)
1988–89	832	8.99	8.92	132.51	130.78	0.036 (0.358)	0.003 (0.053)
1989–90	995	8.88	8.76	129.39	126.97	0.001 (0.997)	0.005 (0.019)
1990–91	941	8.93	8.87	130.53	129.46	0.016 (0.707)	0.002 (0.274)
1991–92	934	9.06	8.92	135.97	132.54	0.154 (0.000)	0.006 (0.000)
1992–93	918	9.22	9.21	139.24	139.67	−0.136 (0.001)	−0.001 (0.614)
1993–94	880	9.14	9.01	138.07	134.35	0.009 (0.832)	0.007 (0.000)
All seasons	7904	9.00	8.92	133.29	131.39	0.006 (0.663)	0.004 (0.000)

where FEO and FEC are individual game forecast errors of the opening and closing lines, MFEO and MFEC are the mean forecast errors of these lines, and μ is an error term (with the usual assumptions). The null hypothesis is that the difference between the two mean square forecast errors is zero. This null requires that the intercept and slope terms are jointly zero. The alternative hypothesis, that MSFEO is larger (smaller) than the MSFEC, requires both coefficients to be nonnegative (nonpositive) and at least one of the coefficients to be strictly positive (negative). Tests on the individual coefficients also provide information about relative forecast accuracy: the t-statistic on the intercept estimate ($\hat{\alpha}$) tests for a significant difference in the mean absolute forecast errors,[11] while the t-statistic for the slope estimate ($\hat{\beta}$) tests whether there is a significant difference in the forecast error variances.

Results of the AGS test are also given in Table III. The results indicate that the MSFEC is significantly smaller than MSFEO for the whole sample of line change games and for seven of the nine seasons considered separately. For most of these seven seasons this superiority occurs because closing line forecast error variances are smaller than those for opening lines (that is, intercept estimates are positive but p-values for the intercept t-statistic do not allow rejection of the null hypothesis, while slope estimates are positive and p-values are sufficiently small to allow rejection of the null). For the 1990–91 season the AGS null hypothesis of equal mean square forecast errors cannot be rejected, and for the 1992–93 season the AGS test indicates that opening line mean absolute forecast errors are significantly smaller than those for closing lines (both parameter estimates are negative and the p-value for the intercept allows rejection of the null).

Although closing lines appear to be statistically superior forecasts of game outcomes relative to opening lines, the actual differences between mean absolute and mean square errors of the two forecasts seem too small to confidently claim that they reflect differences arising from informed trader activity. But aggregate tests of the relative magnitude of forecast errors may not be important here. What matters to bettors is whether or not their bets on a team are on the right side of the line—whether that team wins against a betting line by a half-point or by twenty points is of no importance. The next section develops and reports results for more direct tests of individual betting line changes.

III. The Information Content of Individual Line Changes

Changes in lines from the opening to the closing of the book on games convert bookmakers' forecasts of game outcomes into market forecasts. Because actual game outcomes are observable, we can examine whether these market-driven line changes contain information relevant to the game outcome or are noise. In this section we develop tests of the information content of individual line changes and use these tests on our sample of NBA lines and game outcomes.

[11] The AGS procedure assumes that both mean forecast errors have the same sign. When only one is positive, we add two times the absolute value of the negative forecast error to the dependent variable. This adjustment shifts the constant term so it continues to measure differences in mean absolute forecast errors. For more details, see Hafer, Hein, and MacDonald (1992).

A. Tests of the Information Content of Individual Line Changes

A line movement that makes it more difficult for a given team to beat the betting line indicates that bettors, in the aggregate, believed that team was the superior proposition at the initial line and bet accordingly. Moreover, it is likely that the magnitude of the line change reveals the strength of bettors' aggregate beliefs of the chances of that team beating the opening line. The higher the perceived probability of the team beating the opening line, the larger the betting imbalance, and consequently, the more bookmakers were forced to move the betting line (making the team a larger favorite or smaller underdog) to reduce the attractiveness of betting on that team. These arguments suggest the following tests of line movements.

A.1. Direction of the Line Change

If betting line movements are the result of informed trading, teams that become more favored over the course of betting (those experiencing positive line changes) should have actual winning proportions of bets at opening lines that exceed one-half. Conversely, teams that become less favored (those experiencing negative line changes) should have actual winning proportions at opening lines that are below one-half. On the other hand, if noise trading dominates, these winning proportions may not be different from one-half for either positive or negative line changes.

If opening lines are unbiased and if bettors in the aggregate are rational, actual winning proportions at opening lines should not be different from one-half for no-line change games. However, if opening lines for these games are somehow biased and bettors do not discern these biases, actual winning proportions may differ from one-half.

A.2. Magnitude of the Line Change

If informed traders dominate, teams with positive (negative) line changes should have a greater (smaller) proportion of winning bets at opening lines than at closing lines, *and* these opening line winning proportions should increase (decrease) as the size of the line change increases (decreases). These expectations can be considered in terms of an ordering by line change magnitude. Teams with the largest negative line changes should win significantly less than one-half of bets at opening lines. As line changes increase in magnitude, team winning proportions should increase monotonically. At a zero line change these proportions should equal one-half, and with successively larger positive line changes these proportions should both increase and become significantly greater than one-half.

Finally, if bookmakers allow line changes of sufficient magnitude to correct opening line biases detected by rational bettors, actual winning proportions of bets on these teams at closing lines should not be different from one-half for either positive or negative line changes. However, noise trading

Table IV

Home Team Winning Proportions at Different Line Change Magnitudes

Line changes are defined as the closing line minus the opening line, $\Delta L = (CL - OL)$, from the perspective of the home team. N is the number of games at each line change magnitude. The home team "wins" when the home team's score (HPS) is greater than the visiting team's score (VPS) by more than the respective line: (HPS − VPS) > OL or CL. Ties, where (HPS − VPS) = OL or CL, have been deducted from N in calculating the proportion of home team "wins" against the respective line. The Proportion columns contain the percentage of winning bets on the home team for the various line changes at the respective opening and closing lines. The Z-statistic tests the null hypothesis that the estimated mean proportion equals the expected "fair-bet" proportion of 0.50. The p-value columns give the probability of obtaining a test statistic greater than the Z-statistic.

		Home Team "Beats" OL			Home Team "Beats" CL		
ΔL	N	Proportion	Z-statistic	p-value	Proportion	Z-statistic	p-value
≤−4.0	28	0.25	−2.65	0.008	0.46	−0.38	0.70
−3.5	30	0.37	−1.46	0.14	0.43	−0.76	0.45
−3.0	73	0.39	−1.89	0.06	0.49	−0.12	0.90
−2.5	125	0.43	−1.55	0.12	0.54	0.98	0.33
−2.0	331	0.37	−4.83	0.000	0.43	−2.51	0.01
−1.5	549	0.43	−3.25	0.001	0.49	−0.52	0.60
−1.0	1212	0.47	−2.27	0.02	0.51	0.50	0.62
−0.5	1560	0.48	−1.72	0.08	0.50	−0.05	0.96
0.0	2036	0.51	1.04	0.30	0.51	1.04	0.30
+0.5	1625	0.51	0.40	0.69	0.49	−1.12	0.26
+1.0	1202	0.53	1.81	0.07	0.49	−0.50	0.62
+1.5	592	0.59	4.37	0.000	0.52	1.16	0.25
+2.0	327	0.57	2.35	0.02	0.48	−0.67	0.50
+2.5	135	0.69	4.46	0.000	0.56	1.47	0.14
+3.0	66	0.52	0.37	0.71	0.36	−1.86	0.06
+3.5	30	0.57	0.73	0.47	0.47	−0.37	0.71
≥+4.0	19	0.74	2.06	0.04	0.58	0.69	0.49
	9940						

would be indicated by actual winning proportions against closing lines differing from one-half.

B. Test Results

Test results for our sample of NBA games are presented in Table IV. In this table a positive (negative) line change indicates that the home team became more (less) favored over the course of betting from the opening to the closing of the book. For each line change magnitude the table shows the home team's actual winning proportions of bets at opening and closing lines, and Z-statistics for testing the null hypothesis that these proportions are equal to one-half. To preserve statistical power, line changes greater than or equal to four points (in absolute value) are grouped in this table.

B.1. Direction of the Line Change Test Results

At each individual positive line change the actual home team winning proportion of bets at opening lines is always greater than one-half, and at each individual negative line change this proportion is always less than one-half. For all 3,996 positive line change games, the home team winning proportion of bets at opening lines is just less than 0.54 (Z-statistic of 4.68, p-value less than 0.01), and for the 3,908 negative line change games the home team winning proportion is barely above 0.45 (Z-statistic of −5.85, p-value less than 0.01). Finally, at the 2,036 no line change ($\Delta L = 0$) games the actual winning proportion of teams against betting lines is 0.51. This proportion is not significantly different from the expected proportion (Z-statistic of 1.04, p-value of 0.30).

These results can be summarized succinctly. When betting lines change from the opening to the closing, actual winning proportions of bets at opening lines are significantly higher (lower) than one-half for positive (negative) line changes. When betting lines do not change, actual winning proportions are not significantly different from one-half. It appears that, in the majority of instances, bettors in this market identify and bet more heavily on teams undervalued at opening lines, thereby causing betting lines to adjust in the appropriate direction.

B.2. Magnitude of the Line Change Test Results

At four of the eight individual positive line changes shown in Table IV home team winning proportions at opening lines are significantly higher than one-half at the 0.05 level of significance (and a further proportion is significant at the 0.07 level). Likewise, at four of the eight individual negative line changes home team winning proportions at opening lines are significantly lower than one-half (with a further two significant at the 0.06 and 0.08 levels, respectively). More importantly, as the absolute magnitude of line changes increases, home team winning proportions at opening lines diverge from one-half—with minor exceptions, larger positive line changes have increasingly higher proportions, and smaller negative line changes have increasingly lower proportions.

The contrast between home team winning proportions at opening and closing lines is marked: for both positive and negative line changes, these winning proportions at closing lines appear randomly distributed around one-half. Only two of the sixteen nonzero line changes have home team winning proportions at closing lines significantly different from one-half (p-values of 0.01 and 0.06), and only one of these (at $\Delta L = 3.0$) appears in any way irrational. Here, the winning proportion at opening lines is not significantly different from one-half, but the winning proportion at closing lines is significantly below one-half. These results are striking. In almost all instances, bettors are able to move lines by a magnitude sufficient to remove opening line biases by the close of betting.

C. Aggregate Tests across Line Changes

In order to examine the aggregate expectations of bettors, we present two straightforward tests of line change directions and magnitudes.

C.1. Tests Based on Proportions

We argue above that there is a positive relationship between bettors' aggregate beliefs on the likelihood of teams beating opening lines and changes in betting lines. The ex post representation of this relationship substitutes actual winning proportions of teams at opening lines for the measure of central tendency in the distribution of bettors' subjective probabilities. This representation, in linear form, is:

$$\mathrm{WPO}_{\Delta\mathrm{L}} = \alpha + \beta\,\Delta\mathrm{L} + \epsilon, \tag{2}$$

where $\mathrm{WPO}_{\Delta\mathrm{L}}$ is the actual winning proportion of teams at opening lines for each line change magnitude, $\Delta\mathrm{L}$ is that line change magnitude, and ϵ is an error term (with the usual assumptions). Under a null hypothesis of noise trading, expected coefficients values are $[\alpha, \beta] = [0.5, 0]$. Alternatively, if informed bettors move lines, the slope coefficient will be positive.

These hypotheses reverse when the actual winning proportion of teams at closing lines, $\mathrm{WPC}_{\Delta\mathrm{L}}$, replaces $\mathrm{WPO}_{\Delta\mathrm{L}}$ in the above representation. If informed traders move lines in both the correct direction and by the appropriate magnitude, coefficient values are expected to be $[\alpha, \beta] = [0.5, 0]$. These expectations may not hold if irrational trading moves lines.

Weighted least squares regressions (based on the 26 individual line change magnitudes) for these proportions are:

$$\mathrm{WPO}_{\Delta\mathrm{L}} = \underset{(0.77)}{0.50} + \underset{(0.00)}{0.04}\,\Delta\mathrm{L}, \tag{3}$$

and

$$\mathrm{WPC}_{\Delta\mathrm{L}} = \underset{(0.71)}{0.50} + \underset{(0.52)}{0.00}\,\Delta\mathrm{L}, \tag{4}$$

where p-values for the estimated coefficients are shown in parentheses.[12]

[12] Because the variance of the dependent variable (either $\mathrm{WPO}_{\Delta\mathrm{L}}$ or $\mathrm{WPC}_{\Delta\mathrm{L}}$) is inversely related to the number of line changes at each line change magnitude, weighted least squares estimation is used for these regressions: the jth diagonal element of the variance–covariance matrix, $\Omega(N)$, is σ^2/n_j, where n_j is the number of line changes at the jth line change magnitude, $\Delta\mathrm{L}_j$.

The noise trading joint null hypothesis is decisively rejected at opening lines: the regression F-statistic is 49.89 with an associated p-value of less than 0.01. In this regression, the estimated intercept is not different from a half, but the estimated slope is positive and significant. In contrast, the informed trading joint null hypothesis is not rejected at closing lines (the regression F-statistic is 0.28 with an associated p-value of 0.76). Results for single season regressions (not detailed here for space reasons) are very similar. The noise trading joint null hypothesis for winning proportions at opening lines is rejected at the 0.10 significance level for eight of nine individual seasons (six of nine are rejected at the 0.05 level), while the informed trading joint null hypothesis for winning proportions at closing lines is rejected for only one of the nine seasons (at then only at a p-value of 0.09).

C.2. Tests Based on Forecast Errors

Aggregate bettor behavior causing lines to change can also be examined using Brown and Sauer's (1993b) "pure noise" and "pure fundamentals" hypotheses. In our setting their "pure noise" null hypothesis is that $E\{(AS - OL)|\Delta L\} = 0$ for all values of ΔL. Their alternative hypothesis is $E\{(AS - OL)|\Delta L\} > 0$ for positive line changes, and $E\{(AS - OL)|\Delta L\} < 0$ for negative line changes. For the 3,996 positive line change games the opening line mean forecast error (ordered, like Brown and Sauer, on a home team basis) is 0.98 with a standard deviation of 0.36 (t-value of 2.75 and a p-value less than 0.01). For the 3,908 negative line change games this forecast is -1.15 with a standard error of 0.44 (t-value of -2.61 and p-value less than 0.01). The "pure noise" hypothesis is thus rejected for both line change directions. Brown and Sauer's "pure fundamentals" null hypothesis is that, at each given line change, the line change equals the opening line forecast error, or $E\{(AS - OL)|\Delta L\} = 0$ for all values of ΔL. The mean value for this test is -0.01 (t-value of -0.05). The Brown and Sauer "pure fundamentals" hypothesis cannot be rejected for line changes in our NBA sample. These combined results add to the evidence that bettors appear able to determine and bet on undervalued teams at the opening lines.

IV. Discussion

The above results, we believe, are a strong confirmation of a market in which traders process information into price.[13] Bettors in this market appear able to identify teams whose chances of winning against initial bookmaker lines are undervalued. Further, their betting appears to cause bookmakers to adjust lines sufficiently that by the close of betting these biases are removed. Informed traders are both present and influential in this market.

[13] To be frank, we did not expect results as clear-cut as these. For example, we expected that larger (in absolute value) line changes might contain information, but our priors were that small line changes (of a point or less) were probably noise.

How do these results compare with findings reported in the literature on point spread betting markets? In their study of the NFL betting market, Gandar et al. (1988) conduct a simple, aggregate test of the forecast accuracy of line changes by examining the proportions of line changes moving toward and away from actual game outcomes. For their six season NFL sample, Gandar et al. find only 46.61 percent of 886 line changes move lines toward actual game outcomes (Z-statistic of -2.02, p-value of 0.04). In contrast, 52.13 percent of the 7,904 line changes in our NBA sample move lines toward game outcomes (Z-statistic of 3.71, p-value less than 0.01).[14] The difference between these results is intriguing.[15] Future research into the differences between these markets may be enlightening.

In their examination of the NBA betting market, Brown and Sauer (1993b) looked at game-to-game variations in betting lines rather than the open-to-close betting period price variations examined here. They developed a relative team strength model, and conducted mean forecast error tests on the difference between their model's forecasts of game outcomes and actual game outcomes conditional upon the magnitude of the difference between the model's forecast and the betting line (their unexplained component of betting lines). These forecast errors are found to be directly and proportionately related to actual game outcomes. Brown and Sauer interpret this as a strong indication that game-to-game betting line variations, rather than being noise, represent fundamental information. However, because Brown and Sauer use an intermediate betting line (a line quoted at 5 p.m. Eastern Standard Time rather than a true opening or closing line), the relevant information they show to be priced into their lines could come from bookmakers, the betting public, or both. Our data allow us to draw clearer inferences about information processing of the betting public in this market. While we do not disagree that bookmakers are incorporating most, and sometimes all, of the fundamental information into opening lines, our results indicate that the betting public also processes fundamental information into price.

V. Conclusions

This paper examines price variations, in the form of changes in betting lines from the opening to closing of books on NBA games, with the aim of establishing whether these variations are noise or reflect the activities of

[14] Line changes toward game outcomes also predominate on an individual season basis. In eight of our nine NBA seasons this proportion exceeds one-half, and for four seasons the Z-statistic rejects the null hypothesis of randomness at the 0.05 level (and for a further three seasons the null is rejected at the 0.10 level).

[15] It may be that the dissimilar results arise from additional "noise" in the NFL market, stemming from the greater discreteness in football scoring (where points are commonly scored in threes and sevens) relative to basketball scoring (where points are frequently scored in ones, twos, and threes). Certainly the closing line mean square forecast errors for the NFL reported in Gandar et al. (Table III, p. 1008, 1988) are much larger than those for the NBA reported here.

informed traders. Despite the brevity of this trading market, we show that line changes significantly improve the accuracy of lines as forecasts of actual game outcomes. These line changes are directly and proportionately related to team-winning proportions at opening lines. Moreover, these line changes appear to be of a sufficient magnitude to remove, by the close of the market, forecast biases in opening lines. Collectively, these results demonstrate that price changes in this market are not simply noise. Rather, they contain information that causes prices to more accurately reflect fundamental values. Informed traders are present and influential in this market.

The results raise the issue of the origin of the informed trading. We believe the brief trading period in this market largely rules out information release. For obvious reasons, it also seems unlikely that bookmakers, using public information, misprice opening lines with the frequency found. Therefore, public information sources do not appear to explain the informed betting and leaves us with a conclusion that informed traders either possess private information or are superior to bookmakers in the processing of the information available in this market (a hypothesis consistent with Romer's (1993) model of rational processing of information).

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