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The full moon effect and the efficiency of point-spread betting in the NFL

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By

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Abstract:

This study examines the efficiency of point-spread betting lines of the National Football League, relative to the observed outcome of the games, using data on all regular season games between 1978 and 2007. In addition to replicating and extending the existing literature on the home-underdog bias as well, as the late-season bias, new and significant contributions have been made. This study identifies bias in the lines that is occurring as a result of the lunar cycle. In particular, the home team is being consistently and significantly understated on the day before the full moon creating possible arbitrage opportunities. The models present a full-moon bias that is most relevant the day before the full moon. The bias also changes during the course of a season, and the time span covered by the data set.

1. Introduction

Sports are one of the most popular forms of entertainment in the United States. As of 2003 the sports industry was the 11th largest in the United States with a total of $152 billion in output. Sports betting is a popular form of gambling that has grown very rapidly in the past and continues to gain strength as an industry. In particular, betting on the National Football League (NFL) has been flourishing. In 2003, gamblers bet approximately $17 billion, with about $1 billion bet on the NFL (Wolfers, 2003). Wagers on the NFL accounted for 40% of the sport-betting revenue for legal bookmakers in Nevada in 2001 (Nevada Gaming Control Board, 2002).

The quickly expanding NFL betting industry has sparked the interest of many in the fields of behavioral economics and finance. The wagering patterns of bettors and the efficiency of the market itself are analogous to a variety of other markets, particularly in finance. Profit-seeking investors (bettors) with heterogeneous beliefs come together via a financial intermediary (bookmaker). The price (line) of a financial product (bet) will adjust according to the investing (wagering) distribution.

Biases and inefficiencies in the NFL market must be minimized by bookmakers to prevent the existence of arbitrage opportunities. The literature identifies several factors that create inefficiencies including home-underdog, late-season, cold weather, and bet popularity biases (Borghesi, 2006; Borghesi, 2007; Levitt, 2004; and others). Bookmakers assume a substantial amount of risk and may purposely create inefficient lines to account for particular biases, such as local bettors betting on local teams in large markets (Levitt, 2004). This study examines the efficiency in the NFL betting market as well as biases that exist. Specifically, this study seeks to test whether the lunar cycle impacts betting behavior.

Section 2 will review relevant literature. The data are defined and described in section 3. Section 4 contains the models used in this study, as well as the estimated results obtained using both ordinary least squares (OLS) and probit regression analysis. The conclusion is presented in Section 5 along with unresolved ideas that can be addressed in further research.

2. Literature review

2.1. Betting market fundamentals

Three major types of wagering dominate the commercialized betting industry including pari-mutuel odds, bookmaker odds, and bookmaker point spreads. Pari-mutuel odds systems are commonly found in the horse racing industry and are fundamentally different from the other two. For example, in pari-mutual systems, all wagers are continuously pooled together. The odds are not determined until the horses post and all bets are in. The payoffs are thus homogenous among all winning bettors regardless of how early or late an individual placed his/her bet. Bookmaker odds and point spreads, in contrast, differ from pari-mutuel odds in a sense that the bettors' payoffs are determined when the wager is placed. This is a feature that is generally preferred by gamblers, and is likely the reason pari-mutual odds are not used for major team sporting events.

Bookmaker odds can also be interpreted as payout for a successful wager. They can be bet on directly in the form of a "moneyline" bet or used as a payout condition in point spread bets. The calculations of these odds along with an interpretation of their meaning will be discussed in section 2.2.

There is little debate on how the NFL betting functions in a way that is analogous to capital markets. Jaffe and Winker (1976) compare the two markets in a straightforward manner. Like an investor, the bettor places a wager through an odds maker (broker), at a market price that is in the form of a point spread or "moneyline". As in any marketplace, there is a collection of people with two contrasting opinions that come together via an intermediary entity (sports book or broker) determining an equilibrium price level. The favorite is expected to win by a certain spread and thus has to overcome this handicap in order to win.

The opening lines are generally established using the sports book's expert's forecasts, and possibly the betting direction of "choice" of early bettors. As information (injuries, suspensions, and weather forecasts) accumulates over the week, the distributions of bettors becomes more apparent to the bookies. The lines or odds will move in attempt to properly reflect betting behavior and money flows. For example, if enough bettors see arbitrage opportunities, the distribution of bets will be heavily weighted on one side, thereby generating movements in the lines and odds. In some rare cases, the bookmaker's tools will be unable to stop the lopsided betting and will take the game off the board, stopping any new bets from being placed. This is often caused by extreme and unexpected information developments (such as the sudden injury of a star quarterback), or by potentially fixed games. The closing line takes into account the opening line, accumulated information, and bettor behavior.

Behavior bias is an important concept that is addressed throughout the literature. Borghesi (2007) identifies one such bias as it relates to the relative week in which a game was played during the season. He finds that during the latter portion of the season, the home-underdog wins with much greater frequency. Home underdogs (teams who play at home but are not favored to win) are an anomaly that have historically been analyzed by many scholars (eg. , Dare and Holland, 2004; Grey and Grey, 1997; and others) but Borghesi finds that the effect has an interesting seasonality attribute. In addition to explaining how the dollar volume of bets placed increases as the season gets deeper, he also elaborates on how bettors may discount information regarding a teams recent performance, transactions, and personnel differently throughout a season.

Sauer (1998) identifies other such behavior bias that takes place in a wagering market. Using examples (specifically with horse racing), he states that "wagering markets are fascinating in part because cheering for competitors is linked to loyalty, passion, and other "irrational" concepts (p. 2026)."

The human bias that Sauer identifies can be illustrated in essentially all major team sporting events worldwide. Hardcore fans obtain a sense of belonging and identity in a given team. The merchandise sales, sold out venues in below freezing temperatures, tears, face paint, and drunken bleacher brawls, to such expressions like "my team", all indicate that fans gain great utility from cheering for a team. In some respect, teams represent a fan's own clan going to battle. Expressions like "I live or die with the Bears" arise even though the outcome has little bearing on a fan's personal life, other than pride or monetary gain via betting. It may be an altruistic attribute engrained into a fan's psychology, but regardless, there are strong perceptions (good or bad) sports enthusiasts have for "their" team(s).

Unlike an equity market where investors often trade though clear cut fundamentals and a large information network, many bettors do not have such luxury to some extent. It can be argued that bettors more heavily weigh loyalty and "feelings" as primary motivation for wagering than do those in the equity markets. On the bookies side, every line begins with a number that is possibly erroneous and subject to bias.

2.2. Bookmaker odds and vigorish

Prices are used as indicators of many subtle signals throughout the field of economics, and bookmaker odds are no exceptions. If a game is (perfectly) evenly matched the odds will be +100 (also defined as -100 or 1:1), meaning that there is a 50% chance for either team to be victorious. With these odds, a $1 bet will yield a $1 reward. The more heavily a team is favored to win, the more risk is required to yield the same winnings. For example, if a team is -600, a bettor must risk $6 to win the same $1 return. Assuming no takeout, the underdog in this example would be +600 meaning that a $1 bet would yield a $6 return. Although these odds are easy to interpret, they are not realistic in the betting world.

The tax for placing a bet with a bookie, or "vigorish", is analogous to the ask/bid spread in the securities markets. The generally accepted takeout for legalized sports betting is .1, meaning that a 10 cent tax is collected by the bookmakers for every dollar that is won. This vigorish can manifest itself in a variety of different forms. For example, the odds of an evenly matched game could be: -105 for both teams; or be -110 for one team and -100 for the opposing team. Taking into account bookie vigorish, the proportion of winning bets needed to break-even can be calculated by using equation 1 presented by Vergin et al.(1978) assuming that a bettor must wager 11 dollars to win 10 dollars (a takeout of .1) and p is the probability of the favorite winning assuming an efficient market (i.e. p=.5). This approach is widely accepted throughout the literature.

$$p(10)=(1-p)(11) \qquad (1)$$

The calculation generates the conclusion that a bettor must be successful 52.24% of the time to break even. The key to any successful betting strategy is to overcome the vigorish and win more than 52.24% of the time. Bookies, on the other hand, ideally want to choose a point spread and/or odds such that bettors are equally distributed on both sides. By attaining this balance, the bookmakers assure that profits will be realized in the form of vigorish regardless of the outcome of the game. This balance is emphasized in the work of Gilbert Bassett, Jr.(1981).[1]

[1] There are numerous other betting options such as parlay cards, proposition bets, and special points spread bets. This study is strictly concerned with the efficiency of traditional spread betting.

2.3. The lunar cycle and efficient markets

Like those living in ancient civilization, many modern day scholars have tried to relate lunar cycles to human behaviors and interactions. The lunar cycle spans over a 29.53 day period during which, at one point, the moon is full and at another it is new. Full moons are of particular interest to a broad spectrum of scholars, ranging from the disciplines of biology and psychology, to those in economics and finance.

In finance, Yuan (2006) uses the unique properties of the lunar cycle to investigate how the full moon relates to stock returns among 48 countries. He finds that global returns on a full moon are significantly lower than they are on a new moon. In addition to this full moon effect among countries, Yuan finds that it also intensifies in small cap stocks as opposed to large cap ones. These findings are relevant because small cap stocks are more widely held by individuals (rather than institutions). This means the price can swing more freely with a person's mood from day to day. Both the full moon effect in capital markets and its increased intensity in small cap stocks are a logical analogy of how the full moon may affect sports betting markets.

Investors' moods have long been hypothesized to have effects on financial and economic activity. John Maynard Keynes (1936) tried to describe these moods as "animal spirits" that drive confidence in the economy. The financial literature (Kamstra, et al..2000; Hirshleifer and Shumway, 2003; Coval Shumway, 2005) has attempted to provide evidence of these "animal spirits" by arguing asset prices are effected by mood. For example, Kamstra et al. used the medical condition of seasonal affected disorder to proxy mood as it relates to stock returns. Sunshine and daylight fluctuations have also been used as exogenous proxies for mood changes as they relate to returns in capital markets. Extending this literature, Yuan cleverly uses the full moon as a proxy for investor's moods. He argues that "the lunar effect is an exogenous proxy for mood since lunar phases do not have tangible effects on economic and social activities (p. 4)."

Dichev and Janes (2003) added to the financial literature relating return to the lunar cycle. Their work compares "all major U.S. stock indexes over the last 100 years and for nearly all major stock indexes of 24 other countries over the last 30 years".[2] With a cornucopia of observation at their disposal, Dichev and Janes found that stock market returns during the 15 days surrounding a new moon were nearly twice the size compared to the 15 days surrounding a full moon.

A more complex and abstract analysis of the lunar cycle's relationship to major financial events is presented in Christopher Carolan's book The Spiral Calendar (1992). By deriving relatively complex functions using Fibonacci numbers, the "golden ratio" (a constant that is found throughout nature, also known as Φ), and the lunar cycle, Carlolan attempts to explain panics and crashes. He argues that his creative approach not only does a good job of explaining the past, but it also can be used in out-of-sample forecasting.

On a broader spectrum, the full moon has been associated with the most basic of human functions and activities in the fields of psychology and biology. In biology, menstrual cycles mimic those of lunar cycles (Law, 1986). Testosterone levels in males were also shown to have a direct and distinct pattern that corresponds to the 28-day intervals between full moons. With menstrual cycles and testosterone levels both being

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[2] "The last 100 years" and "the last 30 years" is relative to 2003 when this study was published.

linked to lunar cycles, it is not surprising that fertility in humans also shares a relationship with the moon's orbit (Criss and Marcum, 1981). The relationship between reproduction and lunar cycles can also be conclusively linked to animals as well. For example, the spawning activity in male forktail rabbitfish (Rahman et al. 2002) and golden rabbitfish (Rahman et al., 2000a, b, 2001, 2002) are synchronized with the lunar cycle. Lunar rhythms may also be linked to food and alcohol consumption in humans. De Castro and Pearcey (1995) collected data from a sample of 694 people and found that, relative to a new moon, meal sizes increased 7.8% and alcohol intake decreased 25.9% during a full moon.

Psychology literature extends the connection between lunar cycles and human behavior. Perhaps the most classic of these (connections) comes from the relationship between full moons and "lunacy". Hicks-Caskey and Potter (1991) reports that there is more "acting-out" behavior among institutionalized women during a full moon than otherwise. More objectively, admissions to psychiatric hospitals themselves increase during the days immediately following a full moon (Katzeff 1981, pp. 176-177).

Tasso and Miller (1976) documented that criminal offences committed in major metropolitan areas occur significantly more frequently during a full moon. Crisis calls are also placed with more frequency according to a study by Weiskott (1974). Liber (1978) showed that murder and other violent crimes peak during full moons and immediately following new moons in Dade County, Florida.

The full moon stigma, enhanced by myths of werewolves and terms like "lunacy" and "lunatic", was attempted to be quantified by a survey conducted by Rotten and Kelly

(1985).[3] It was shown that 49.4% of all respondents and 74% of psychiatric nurses believe in a full moon effect. A similar survey shows that 64% of physicians and 80% of nurses acknowledge a full moon phenomenon according to Danzl (1987). These opinions may be propelled because general practice consultations themselves increase during a full moon (Neal and Colledge. 2000) as well as trips to hospital emergency rooms (Katzeff 1981, pp. 109-110).

Like a blimp that provides aerial television coverage, the moon hangs over those playing and attending major sporting events. Ice hockey and football are perhaps the most physical of all of the professional team sports. During the 1976-77 season of the World Hockey Association, penalty minutes (mostly for fighting, high sticking, and other aggression related penalties) peaked on the night of a full moon and fell below average during a new moon (Katzeff 1981, pp. 184-186). The relationship Katzeff found between the full moon and penalty time in ice hockey suggests that the lunar cycle may affect the outcome of team sporting events and hence potentially the efficiency of betting markets. One of the main objectives of this study is to test whether the lunar cycle impacts the outcome of games played in the National Football League that is not accounted for by the betting lines (Levitt, 2004).

[3] Similar results found by Vance (1995).

3. Data description

This study uses data on the closing lines and outcome for National Football League games played during the 30 regular seasons between the years 1978-2007. The data regarding the NFL statistics and lines were gathered from repole.com.[4] Given the fact that game statistics, including the final scores, are objective and concrete, there is little concern for bias. The lines, although more subjective, are also very reliable and unbiased. For example, the lines are consistent with the closing lines in Nevada casinos. NFL lines move closely together and Nevada lines are generally accepted as the benchmark lines. The data on the full moons were gathered from life-cycles-destiny.com.[5] The line (*line*) is traditionally calculated by subtracting the predicted score of the home team (*psh*) from the predicted score of the visiting team (*psv*), mathematically expressed as:

$$line=psv-psh \tag{2}$$

Given equation 2, a negative line implies that the home team is favored (visitor underdog) and a positive line indicates that the visiting team is favored (home underdog).

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[4] http://www.repole.com/sun4cast/samples/csvpage.html

[5] http://www.life-cycles-destiny.com/dw/full-moon-phases-calendar-chart.html. The time of the day that a full moon occurred is not accounted for in this study. For example, the data does not differentiate if a full moon occurs at 12:01am or at 11:59pm on a given day. This may cause slight bias in the data but is not a concern.

Consistent with the calculation of *line*, the outcome (*outcome*) of a game is calculated by subtracting the observed score of the home team (*osh*) from the observed score of the visiting team (*osv*), mathematically expressed as:

$$outcome=osv-osh \qquad (3)$$

It is important to note that pick'em games occur when *line*=0 and "pushes" or "ties" occur when *line=outcome.* The following tables provide descriptive statistics for the point spreads, and reports winning bets placed on the home team, i.e. *outcome<line*.

Table 1

Basic Winning percentages

	Games	*Percentage*	*Non-pushes*	*Home Wins*	*Ties*	*Winning pct.*
All Games	6894	100%		3372	189	50.29%
Home Favorite	4582	66.50%	4455	2173	127	48.78%
Home Underdogs	2183	31.67%	2121	1131	62	53.32%
Pick'em Games	129	1.87%	129	68	0	52.71%

Table 1 shows that out of 6894 games played in the regular season between the 1978-2007 seasons, the home team beat the spread 50.29% of the time. The home team was favored 66.5% of the time, but home underdogs beat the spread with more consistency, winning 53.32% of the time.[6]

[6] The totals lines, or over/under, allow a bettor to wager on the total points that will be scored in a football game. These totals lines (*totalsline*) along with the actual number of points scored in a game (named *actualtotal*, and calculated by the sum of both teams' scores) are included in the data. The over covered 46.7% of the time, the under covered 48.1% of the time, and 5.2% of the time a push occurred.

Data involving lunar cycles were also gathered for this paper. In conjunction with the full moon, a variety of dummy variables were generated. First, there are five dummy variables that have values of 1 when the game falls on a specified day relative to a full moon. These dummies indicate whether a game was played two days before a full moon, one day before a full moon, the day of a full moon, one day after a full moon, and two days after a full moon and are named *fmneg2*, *fmneg1*, *fm*, *fmpos1,* and *fmpos2,* respectively. Secondly, there are two variables that have values that represent the number of days away from a full moon that a given game was played. The variable named '*daysfm*' has a value between -15 and 15, where a negative number represents that the game occurred on a day approaching a full moon.

Table 2

Variables and Descriptive Statistics

Variable Name	*Description*	*Observations*	*Mean*	*Standard Deviation*
outcome	*Visitor-home (observed)*	6894	-2.807	14.427
line	*visitor-home (predicted)*	6894	-2.504	5.817
totalsoutcome	*visitor+home (observed)*	6670	41.312	14.26
totalsline	*visitor+home (predicted)*	6670	40.63	4.186
z	*outcome-line*	6894	-0.303	13.29
fmneg2	*=1 if 2 days before full moon*	212	.0308	.1727
fmneg1	*=1 if 1 day before full moon*	244	.0354	.1848
fm	*=1 if day of full moon*	251	.0364	.1873
fmpos1	*=1 if 1 day after full moon*	215	.0312	.1738
fmpos2	*=2 if 2 days after full moon*	208	.0302	.1711

Table 2 provides descriptive statistics for the variables used in this analysis. It clearly shows that the standard deviation in the observed outcome (14.42) is much larger than that of their corresponding line (5.81). In addition, the descriptive statistics also show a 2.8 point home field advantage, in which 2.5 points are handicapped by the line, on average, resulting in a difference, z, of -0.203. The average total line over 6670 observations was 41.3 points while the average actual outcome was 40.6.

The data were treated as time-series data and all of the variables were tested for stationarity using a Dickey-Fuller test for unit roots. All variables were found to be stationary. This is not surprising given the fact that the line and outcome are essentially differences themselves and their values should be distributed around a common mean.

4. Models and results

4.1. The nature of efficiency of the sports betting market

There are a variety of different ways to determine if a market is behaving efficiently. Boulier (2006) describes three possible inquisitions including: "(1) is the market's point spread an unbiased predictor of the actual point difference? (2) are the fundamentals that determine the outcome of games fully incorporated into the betting line? and (3) are there betting strategies that can beat the market?"

Most of the sports-betting literature has focused on Boulier's first question. For example, it is generally accepted that in an efficient market the line will be an excellent predictor of the outcome of a game. More specifically, the line should have a nearly perfect linear relationship with the outcome of a game. This can be statistically shown with the following regression:

$$outcome_{jt}=\beta_0+\beta_1 line_{jt}+\varepsilon_{jt} \quad (4)$$

Outcome$_{jt}$ represents the outcome for game *j* at time *t* as defined in equation (3). *Line*$_{jt}$ is the bookmakers' line for game *j* at time *t* as defined in equation (2). Under efficiency, implying that every 1 point the home team is predicted to win (lose) by, the home team should actually win (lose) by one point.

A coefficient of 1 for β_1, the coefficient on *line,* and 0 for β_0, the constant, reflects a perfect linear relationship but it does not necessarily mean that the market is acting efficiently. For example, imagine the outcomes of a week in which 14 games are played. Suppose in 7 of these games the home teams dramatically beat the spread and in the other 7 games the home teams did not cover and lost by large amounts. Even though the line was not necessarily efficient, its coefficient may still be close to 1. Although there is some validity to the argument, real-world analysis seems to nullify the critic's argument. For instance, if this were to be consistently true, there would be tremendous arbitrage opportunities that would put the bookmakers out of business. Sports books are profitable because there are few opportunities for arbitrage that cannot be overcome by the vigorish. Over a large sample, such as the one used in this paper, the coefficient should reflect true market efficiency.

4.2. Calculating simple efficiency

An efficient line should take into account every aspect that affects a football game. In other words, nearly all tangible and intangible factors (including bias) that affect the outcome of a game will be reflected in the line. To test this, equation 4 is estimated using OLS both with and without a constant term:

$$outcome_{jt}=\beta_0+\beta_1 line_{jt}+\varepsilon_{jt} \qquad (4)$$

$$outcome_{jt}=-.38996+.96528 line_{jt}$$ [7]

(.17428)** (.0275)*** [8][9]

R^2=.1515

Excluding the constant, which is commonly done in the literature, yields:

$$outcome_{jt}=.98963 line_{jt} \qquad (5)$$ [10]

(.0252854)***

R^2=.1818

Using a similar equation the efficiency of the totals, both lines and outcome, can be estimated and interpreted in a similar manner. In this equation the constant term is always set to zero based on the logic set forth in section 4.1:

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[7] A Breusch-Godfrey Lagrange Multiplier test has been performed to detect for serial correlation. With a chi² value of .502 a null hypothesis that no serial correlation exists cannot be rejected. A Breusch-Pagen heteroscedasticity test yields a chi-squared value of .57 which fails to reject the null of no heteroscedasticity.

[8] *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. Standard errors are listed inside parenthesis.

[9] All of the line coefficients were tested (F-test) to see if equal to 1. It can be concluded that none of them are statistically different than 1 at any level.

[10] A Breusch-Godfrey Lagrange Multiplier test has been performed to detect for serial correlation. With a chi² value of .607 a null hypothesis that no serial correlation exists can not be rejected.

$$totalsoutcome_{jt}=\beta_1 totalsline_{jt}+\varepsilon_{jt} \qquad (6)$$

$$totalsoutcome_{jt}=\underset{(.00415)^{***}}{1.015}totalsline_{jt}$$ [11]

R^2=.9000

F-tests performed on *line* and *totalsline* fail to reject the null hypotheses that all coefficients are equal to 1. Consistent with other sports-betting studies, over the entire sample both the line and the totals line seem to be efficiently predicting the respective observed outcomes on average.

4.3 Lunar cycles and efficiency

To take into account the possible effects of a full moon, an equation similar to those presented above is eliminated with the addition of a full moon dummy. The dummy itself changes depending on the day a football game was played, relative to a full moon, and reflects the penalty/premium, on average, for home teams playing on that particular day. The following equation is obtained by adding a full moon dummy to equation 1:

$$outcome_{jt}=\beta_0+\beta_1 line_{jt}+\beta_2 fm_{jt}+\varepsilon_{jt} \qquad (7)$$

[11] A Breusch-Godfrey Lagrange Multiplier test has been performed to detect for serial correlation. With a chi² value of 2.119 and a corresponding probability of .1454 a null hypothesis that no serial correlation exists can not be rejected.

The coefficient and significance of this full moon dummy (*fm)* is particularly interesting because it reflects factors that affect a football game due to a full moon that may not be accounted for by the line. Significance in the coefficient suggests that there exists inefficiency in the spread-setting market. The possible explanations for this inefficiency will be presented in the conclusion of this paper.

The sign of the *fm* term is also important because it determines the direction of the inefficiency relative to the home team. Recall from equations (2) and (3) that *line* and *outcome* are defined as visitor-home. Therefore, a negative sign will indicate that the line understates (overstates) the home (visiting) team and a positive sign will imply that the line overstates (understates) the home (visiting) team.

In equation (7) *fm* is allowed to vary by up to two days before and after the actual full moon. Table 3 provides the estimates obtained using OLS regression analysis. Equation (7) was estimated both with and without a constant. The results were practically identical. For ease of presentation all results are reported when the constant was excluded while only the statistically significant results are reported when the constant was added to the regression.

Table 3

Regression Results From Equation 3

	β_1		β_2	
Dummy Used	*Coefficient*	*SE(significance)*[12]	*Dummy*	*SE(significance)*
2 days before fm	0.9922	.0254(***)	1.212	0.9157
1 day before fm	0.98431	.0254(***)	-2.307	.8533(***)
Day of the fm	0.9892	.0254(***)	-0.1831	0.8421
1 day before and day of fm	0.9837	.0254(***)	-1.239	.6013(**)
1 day after fm	0.9888	.0254(***)	-0.328	0.9107
2 days after fm	0.9914	.0253(***)	0.9914	0.9238
1 day before fm (w/ constant)	0.9651	.0257(***)	-2.039	.8660(**)

Table 3 contains many interesting results. As expected, all of the *line* coefficients are significant at a 99% confidence level and have a value that is very close to 1. As interpreted before, this means that the line is doing a good job of predicting the outcome of a game, on average.

The results for the *fm* terms are profound. In those games played exactly one day before a full moon, a highly significant full moon effect occurs. More specifically, the line understates the home team by 2.307 points on average (2.039 points when a constant term is included). This highly significant understating of the home team is important because it suggests inefficiency in a clear and precise fashion.

When a dummy is created identifying games occurring a day before and the day of a full moon, similar results are obtained. Here the home team is still understated but with less magnitude and significance: nevertheless, the results are pertinent.

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[12] Using f-tests all of the line coefficients are not statistically different than 1.

To reinforce the significance of a full moon effect, parametric mean-comparison tests (t-test) and non-parametric Wilcoxon matched-pairs signed-ranks tests (signrank) have been performed to see if the outcome is equal to the line during specified days relative to a full moon. Theoretically, the outcome should not be significantly different than the line regardless of the day a football game is played relative to a full moon. The mean-comparison test compares the equality of means and allows for unequal variances given that the variance in outcome, 208.1, is much larger than the variance in the line, 33.6 (see Table 2). A non-parametric Wilcoxon matched-pairs signed-ranks test has also been performed to test the equality of matched pairs of observations. The results are presented in table 4.

Table 4

Parametric and Non-parametric Tests for Equality of Line and Outcome

Gameday relative to the full moon	Signrank[13]	t-test[14]
fmneg2	1.440	1.085
fmneg1	-2.690(***)	-2.238(**)
fmzero	-.407	-.147
fmpos1	.015	-.293
fmpos2	1.235	.9484

The results presented in this table confirm the results using equation (7). Although table 4 does not suggest a full moon effect on the day of the full moon, there is clearly distortion to the difference between the outcome and the line occurring on the day before a full moon. The full moon effect occurs in an asymmetric way given it is strongly present the day before and not the day after a full moon.

[13] Z-scores and two-tailed test relative to a critical z-score value with a null hypothesis that the mean difference is equal to 0 are reported.

[14] T-stats and two-tailed t-test with a null hypothesis that the mean difference is equal to 0 are reported.

4.4. Home-underdog bias

Much of the existing literature identifies a bias to the home team depending on whether they are the favorite or underdog. Gray and Gray (1997) among others have shown that the spread does not occur independently of venue. The following equation controls for the fact that a home team is more likely to be a favorite:

$$outcome_{jt}=\beta_0+\beta_1 home_{jt}+\beta_2 favorite_{jt}+\varepsilon_{jt} \qquad (8)$$

Where the variable home is a dummy that is equal to 1 if the team is a home team, 0 if otherwise; and the variable favorite is a dummy that is equal to 1 if the team is a favorite, 0 if otherwise. Dare and MacDonald (1996) and later Dare and Holland (2004) extended this model to properly account for the interrelationship that exists among the venue relative to favorite and the underdog.

Dare and Holland show that a home-underdog bias is present throughout the NFL. Equation (4) can be expanded to control for home-favorite and home under-dog biases with the use of dummy variables (dummies are equal to 1 if the home team is an underdog or favorite respectively).[15]

$$outcome_{jt}=\beta_1 line_{jt}+\beta_2 homefavorite_{jt}+\beta_3 homeunderdog_{jt}+\varepsilon_{jt} \qquad (9)$$

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[15] The constant term in equation 4 should equal zero and is omitted to avoid perfect multicolinearity.

Estimating equation (9) yields the following results:

$$outcome_{jt}=1.05line_{jt}+.233homefavorite_{jt}-1.07homeunderdog_{jt}$$

$$(04912)^{***}\quad(.350071)\qquad(.35952)^{***}$$

[16]

R^2=.183

Consistent with the findings of Dare and Holland and other previous literature, there is a significant home-underdog bias. For example, a coefficient of -1.07 suggests that the line understates home underdogs by 1.07 points on average.

By including full moon dummies, equation (9) can be extended and estimated using OLS as follows:

$$outcome_{jt}=\beta_1 line_{jt}+\beta_2 homefavorite_{jt}+\beta_3 homeunderdog_{jt}+\beta_4 fmneg1_{jt}+\varepsilon_{jt} \qquad (10)$$

$$outcome_{jt}=1.05line_{jt}+.3142homefavorite_{jt}-1.013homeunderdog_{jt}-2.057fmneg1_{jt}$$

$$(.0491)^{***}\quad(.3516)\qquad(.3603)^{***}\qquad(.8653)^{**}$$

[17]

R^2=.183

The full moon dummy significantly adds to the existing home-underdog bias. For example, on the games played 1 day before the full moon the home-underdog team is being understated by 3.07 points on average (1.013 points for being a home-underdog

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[16] Using an F-test if the coefficient on line is equal to 1 yields a probability of .3047 which is insignificant at all levels.

[17] Using an F-test if the coefficient on line is equal to 1 yields a probability of .295 which is insignificant at all levels.

and 2.057 points for playing on the day before a full moon). These results reiterate the full moon effect and suggest even greater arbitrage opportunities.

Equation (10) can be expanded and rearranged to be expressed in a similar manner to Dare and Holland and other recent betting-market studies. Specifically, subtracting $line_{jt}$ from both sides yields:

$$z_{jt}=\gamma_1 line_{jt}+\beta_2 homefavorite_{jt}+\beta_3 homeunderdog_{jt}+\beta_4 fm_{jt}+\varepsilon_{jt} \quad (11)$$ [18]

Where z_{jt} is defined as $outcome_{jt}-line_{jt}$ and $\gamma_1=(\beta_1-1)$. In equation (11), z_{jt} represents the degree of inefficiency that exists in the NFL betting market. Under market efficiency all coefficients in equation (11) should equal 0.

Estimating equation (11) without the full moon dummy to replicate the results of Dare and Holland and others yields:

$$z_{jt}=\underset{(.0491)}{.0504}line_{jt}+\underset{(.3501)}{.2332}homefavorite_{jt}-\underset{(.3595)^{***}}{1.074}homeunderdog_{jt}$$

$R^2=.0015$

These results, which are similar to those found by Dare and Holland and others, show that the inefficiency term (z_{jt}) still shows a home-underdog bias. The home-underdog bias understates the home team by 1.074 points and is greatly significant which

[18] Where $\gamma 1=(\beta 1-1)$

is consistent with the literature and previously obtained results. Adding the full moon dummy that is equal to one on the day before a full moon yields the following:

$$z_{jt}=.0514\,line_{jt}+.3142\,homefavorite_{jt}-1.013\,homeunderdog_{jt}-2.057\,fmneg1_{jt}$$

(.0491) (.3516) (.3603)*** (.8653)**

R^2=.0015

The results are virtually unchanged, except for the fact that the added full moon dummy is significantly understating the home team by 2.057 points on the day before a full moon.

4.5. Probit modeling

Equation (11) suggests a logical transition into probit modeling. Similar to the work of Dare and Holland, a new difference between the outcome and the line (z) can be easily transformed into a dummy variable (w) that is equal to 1 if the home team covers, and equal to 0 if the home team does not cover.[19] [20]

If a market is efficient there exist little to no arbitrage opportunities. Using this logic the NFL football betting market should lack profit making opportunities if it is to be efficient and these full moon and home-underdog effects should not exist. To clearly identify arbitrage opportunities the data can be analyzed in a way that takes into consideration the argument that the returns on a winning bet are the same regardless of

[19]Pushes are excluded (non-observations) in this dummy variable but are accounted for later in the study.
[20] Dare and Holland defined the w variable as 1 if the favorite covered and 0 if otherwise because they defined the line and outcome as favorite-underdog rather than visitor-home . Defining the variables as done in this study yields identical conclusions.

the magnitude of the victory. Many argue that it is irrelevant by how many points a team covers the spread because the return on a winning bet is constant regardless of how many points a team wins by. The probit is used to capture this. The literature uses probit models, such as the following, to identify the efficiency of the NFL lines relative to the outcome of the game:

$$w_{jt}=(\beta_1-1)line_{jt}+\varepsilon_{jt} \tag{12}$$

where, as noted above, $w_{jt}=1$ if $z_{jt}<0$, i.e. the home team covers the spread. As before, the model can be modified to include a full moon dummy term resulting in equation 13. The probit models were estimated separately using all of the full moon dummies, but, as with OLS, only the day before a full moon yields significant results.

$$w_{jt}=(\beta_1-1)line_{jt}+\beta_2 fmneg1_{jt}+\varepsilon_{jt} \tag{13}$$

Estimating equation (13) yields:

$$w_{jt}=\underset{(.00242)^{***}}{.0089}line_{jt}+\underset{(.0816)^{*}}{1.548}fmneg1_{jt} \tag{14}$$ [21]

The probit estimation continues to show that the lunar cycle affects the outcome of a regular season game in the NFL. The positive sign on the coefficient for the full

[21] Marginal effects: w(pr)=.4933 line= .0035 (.00097)*** fmneg1=.0616(.03227)*

moon term suggests that the home team is more likely to win on the day before a full moon.[22]

The probit model does not directly quantify line efficiency but rather indirectly suggests that the line is not efficient for games played on the day before a full moon. For example, an optimal line will give a bettor a 50% chance of correctly choosing the winning team. When the marginal effects of this probit model are calculated, the winning percentage for bets on the home team is shown to be 49.33% which is nearly perfectly efficient. Although the line functions properly on average, the probit model shows that the winning percentage for those betting on the home team will go up 6.12% on the day before a full moon. This means that the home team will cover 55.45% of the time on the day before the full moon holding all else constant.

Although the use of probit modeling is gaining popularity in the line efficiency literature, it is not a perfect substitute for OLS modeling. For example, probit modeling disregards the magnitude by which a team wins and simply describes each game as if the home team covered or not. A probit model essentially treats a "lock", or a team that covers by a comfortable amount, and a team that barely covers the same. It is true a bettor does not necessarily care about the magnitude of a victory, but it may play an important role in his decision whether to bet on a team and also the amount wagered. In addition the bookies themselves are concerned about the magnitude of their error in the line because they may want to adjust their models accordingly.

[22] A probit model was performed including a home favorite and home underdog term of which both terms were highly insignificant. The full moon dummy that is equal to 1 on the day before the full moon was almost significant at the 10% level with a p-value of .111.

Since the probit model does not account for the magnitude of a victory the full moon effect may be somewhat diluted. For example, if the home teams constantly win by a large amount on the days before a full moon, or lose by only a small amount, the probit model will leave out a lot of the bias that may actually exist. That is, the winning percentage might be relatively normal, but the mean of the difference between the line and the outcome may be heavily skewed in favor of the home team. Nevertheless, the probit model still shows a statically significant full moon effect that is understating the home team on the day before the full moon.

4.6. Betting strategies and arbitrage opportunities

The biases that have been identified above open up the doors for potential profit making betting strategies. To identify these opportunities the data must be categorized to correspond to different strategies. In section 3 the data was split into three subsets including games where the home teams were favorites, where the home teams were underdogs, and when the games were pick'ems. Table 5 shows winning percentages for betting on the home team in each of their categories and doing so on the day before the full moon.

Table 5

Winning Percentages

	Winning Percentage	*n*	*95% confidence interval* *Lower bound*	*Upper bound*	*Null hypothesis value*[23 24] *0.5*	*0.525*
Home Team	0.5029	6705	0.4909	0.5148	.4763	-3.45
-using fmneg1	0.5523	239	0.4888	0.6158	1.622(**)	.847
Home Favorite	0.4878	4455	0.473	0.5024	-1.633	-4.84
-using fmneg1	0.5549	164	0.478	0.6318	1.41(**)	.768
Home Underdog	0.5332	2121	0.512	0.5545	3.067(***)	.853
-using fmneg1	0.559	68	0.4377	0.6799	.970	.558
Pick'em Games	0.5271	129	0.4398	0.6144	.6148	.071

For an arbitrage opportunity to exist with takeout of .1, a betting strategy must be successful over 52.5% of the time. The results above provide the average winning percentage, a 95% confidence interval, and F-test for whether the winning percentage is equal to a 50% or the 52.5% cutoff point that is needed to overcome bookie vigorish.

Table 5 continues to reiterate both a home-underdog bias as well as the full moon effect occurring the day before a full moon is present. Over all 6705 non-pushed observations, the home team covered the spread 50.29% of the time, which indirectly implies that the line was acting very efficiently. The winning percentage for the home team jumped up to 55.2% if the game was played on the day before the full moon. The home-underdog covered 53.3% of the time in all games and 55.9% of the time on the day before a full moon. The results in this section suggest that the efficiency of the line breaks down for both home-underdogs and home teams that play on the day before a full

[23] T-stats and one-tailed t-tests with a null hypothesis that the winning percentage is less than or equal to the specified critical value. The level of significance is denoted in parenthesis.
[24] A one-tail test was used because a bettor must exceed a cutoff winning percentage to be profitable.

moon. However, none of the F-tests were able to reject a null hypothesis that the winning percentage was equal to 52.5%.

4.7. The full moon effect on efficiency over time

The line has previously been shown to be inefficient on the day immediately preceding the full moon. By splitting the data into two roughly even subsets and using *fmneg1* as the full moon dummy, statistical breaks and changes in the magnitude of the full moon effect can be calculated over time. The two subsets contain those games that were played before and after the beginning of 1994 season (1978-1993 contains 3416 observations and 1994-2006 contains 3477 observations). The cutoff point of 1994 was chosen for two reasons that will be elaborated on later in this section. Using the basic model the following OLS regression results are obtained:

From 1978-1993:

$$outcome_{jt}=\underset{(.0717)^{***}}{1.013}line_{jt}\underset{(.5126)}{-.032}homefavorite_{jt}\underset{(.5210)^{**}}{-1.2014}homeunderdog_{jt}\underset{(1.257)}{-.767}fmneg1_{jt} \quad (15)$$

[25]

$R^2=.173$

From 1994-2006:

$$outcome_{jt}=\underset{(.0673)^{***}}{1.088}line_{jt}\underset{(.4827)}{+.6595}homefavorite_{jt}\underset{(.4988)^{*}}{-.8469}homeunderdog_{jt}\underset{(1.193)^{***}}{-3.298}fmneg1_{jt} \quad (16)$$

$R^2=.196$

[25] In both regressions the coefficient on the line term was not significantly different than 1 at any level using an F-test.

The results above are interesting for many reasons. For example, in both the early and latter portions of the data, the line was not statistically different than 1, there was no home favorite bias, and there was a significant home-underdog bias which understated the home team as expected (and shown throughout this study and the existing literature). The coefficient on the full moon dummy dramatically changed in the late half of the sample compared to the early part of the sample. Between the 1978-1993 seasons there was no full moon effect occurring the day before a full moon, but between the 1994-2006 seasons, the full moon effect was large. For example, in the more recent years, the home team was understated by 3.298 points on the day before a full moon. This unaccounted for bias is larger in magnitude than the average home field advantage (2.807) itself.

To further identify this statistical break an in-sample winning path is presented in Figure 1:

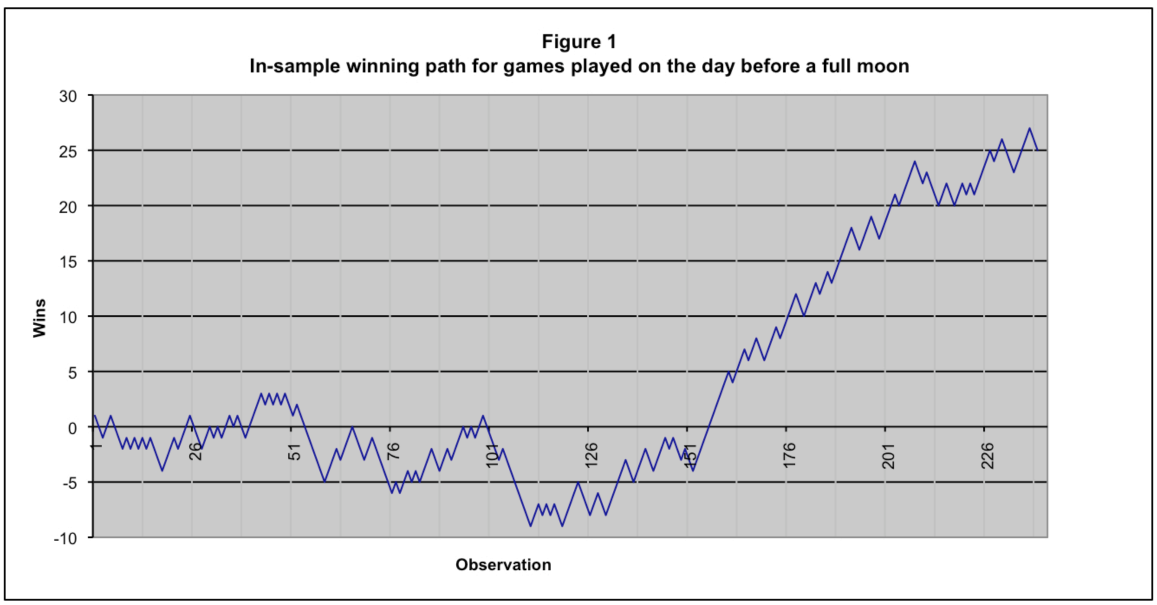

Figure 1 shows the winning path of a bettor that places a bet on the home team on the day before a full moon throughout the sample. If the home team covers (does not cover) the line moves up (down) 1 unit, and a push will leave the line unchanged. The line has a minimum point of -9 and a maximum point of 27. From observation 1(1978) to observation 151 (1986) the line varies around 0, which is expected if there is a 50% probability of winning. From observation 151(1986) through the end of the sample there is a clear and consistent upward sloping trend that arises.[26] The consistent winning strategy shown in the latter portion of the sample clearly implies a bias occurring on the day before a full moon.

Borghesi (2007) examines both the home-underdog bias over time as well as a more original seasonal component that seems to amplify the bias. Borghesi split his data into four 5 year periods between the 1981-2000 seasons. He showed how the most recent subset (1996-2000) displayed the largest home-underdog bias.[27] Over the twenty year period Borghesi found that the home-underdogs won 53.13% of the time which is consistent with the findings of this study (53.33% between the 1978-2006 seasons).

This change in the full moon effect over time is as astounding as it is extreme. Who is affected by the lunar cycle precisely on the day before a full moon that is creating this inefficiency that understates the home team? Are the bookies themselves making inefficient lines? Are the bettors poorly judging the game causing the line to move in an inefficient manner? Are the home fans more intense? Are the visiting teams less

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[26] Observation 180 is the first game in 1994 where the data was split.
[27] He showed the magnitude of the bias between 1996-2000 to be a 6.92 points understating the home team.

enthusiastic about the game or are they getting even worse sleep than usual away from home? Are the home teams more excited and emotional?

Although many of these questions are beyond the breadth of this study, one possible explanation is examined. As presented in the literature review, the lunar cycle has been said to affect a plethora of functions in humans as well as in animals. Human emotions and aggressive behaviors are among the activities that are said to be intensified by the lunar cycle, particularly on and around a full moon. Given the emotional and physical nature of football, it is logical that the lunar cycle may affect the outcome of a game.

The reasoning for splitting the data into two subsets, using the year 1994 as a cutoff, was twofold. First and most obviously, it was the year that would make the data almost equal in the number of observations. Secondly, the year was chosen because the NFL publicly recognized the severity of steroid usage in the league and dramatically tightened the policy against it in 1994. Not only were steroids widely used by 1994, the use of a particular kind of steroid, Human Growth Hormone (HGH), was being introduced and adapted into the world as a performance enhancing substance. Steroids, especially HGH, are well known for dramatically increasing the user's aggression and emotional levels. Consequently, the full moon effect combined with steroid use may potentially have a synergistic effect that is unaccounted for by the bookies. If the steroid effect is indeed amplified the day before the full moon in a way that is advantageous to the home team, changes over time may be expected with the evolution of the drugs and their use in the National Football League.

The full moon may potentially serve as a proxy for steroid usage in the NFL. Performance enhancing substances drastically change the dynamics of a game and there is little or no data on the issue. Since the bookies do not have an efficient way to quantify the usage of performance enhancing substances among teams, it is likely that there may be inefficiencies in the lines.

Given the unknown distribution of the drug use among the teams in the league, the advantages may be picked up as a home field advantage, or a team's handicap, if not canceled out completely. For example, a team's advantage created by steroids would likely be picked up by the bookies over time in the form of a team's handicap or power ratings. In addition, the home field advantage would likely begin to account for the steroid factor if it indeed did give the home team an edge. Regardless of its manifestation, any steroid effect is either washed away or indirectly picked up in the model. If this is true, the full moon dummy may be a clever proxy because the effects are likely intensified with the lunar cycle. The significance of these finding may suggest that the current models that are being used to create the lines contain missing variable bias that is being created by lunar cycles, or as this section suggests, steroid usage.

4.8. Late season bias and the full moon

The efficiency of the sports betting market may not only be changing over time, but is also suggested to have a seasonal component as well. Borghesi (2007) indentifies a home-underdog bias that intensifies during the games played late in the season.[28] Borgehsi used playoff data in his analysis which may bias his results. Playoff games may not be comparable to regular season games for a variety of reasons. For example, there is selection bias in the sense that only the top teams in the league make it to the playoffs. Playoff games not only attract more national attention, they also attract a much larger volume in betting activity. From a player's and coach's perspective, the game itself is different because the emotionally charged atmosphere of "playoff football" is present. The use of playoff games as a continuation of the regular season, as Borghesi suggests, is fundamentally flawed and must be adjusted.

This study will define late season games as those occurring the last 4 weeks of the season. In addition to adding to the work of Borghesi, Table 6 looks at those games that were played both the day before a full moon, as well as within the last 4 weeks of the season.

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[28] Borghesi includes playoff data and defines a late season games as occurring between week 15-18. He suggests that the bias may be caused by cold weather.

Table 6

Late Season Bias

Subset Used	n	Winning Percentage	95% confidence interval Lower bound	Upper bound	Null hypothesis value[29] 0.5	0.525
For all games						
All games	1747	0.5152	0.4917	0.5386	1.268	-.822
Home Favorite	1162	0.4974	0.4686	0.5262	-.176	-1.880
Home Underdog	556	0.5504	0.5089	0.5918	2.385(***)	1.201
Pick'em	29	0.5517	0.3592	0.7442	.550	.284
If the game was played the day before a full moon						
All games	80	0.6375	0.5299	0.7452	2.542(***)	2.08(**)
Home Favorite	62	0.5977	0.4712	0.7224	1.541(*)	1.143
Home Underdog	17	0.7647	0.5399	0.9895	2.496(**)	2.26(**)
Pick'em	1	1	-	-	-	-

The late-season home-underdog bias, as Borghesi suggests, still exists when using a larger data set and redefining a "late-season" game. More specifically, 55.04% of home-underdogs playing in a late-season game covered the point spread. This betting strategy is statistically significant (profitable) using 50% as a cutoff point, but falls just outside a significant range using the traditional 52.5% cutoff point. Regardless of the insignificance accounting for bookie vigorish, the findings are relevant and consistent with previous literature.

When the full moon effect is added to the model, the results become staggering. Of the games that were played late in the season on the day before a full moon, the home team covered 63.8% of the time. This winning percentage is significantly above both the

[29] T-stats and one-tailed t-tests with a null hypothesis that the winning percentage is less than or equal to the specified critical value are reported. The level of significance is noted in parenthesis.

50% and 52.5% cutoff point needed to make a profit. More dramatically, home-underdogs playing on the day before a full moon late in the season cover the spread 76.47% of the time. Although there were only 17 times when this situation occurred throughout the sample size, this betting strategy would be very profitable even with a typical takeout level. The lunar effect, occurring the day before the full moon, is present regardless of when or how the data are looked at.

5. Conclusion and Future Explorations

This study not only replicates and extends existing literature on the efficiency of sports betting in the National Football League, but it also identifies and quantifies a full moon effect. More specifically, this study shows that there is a strong and consistent lunar effect occurring on the day before a full moon. A variety of models were used, all of which reached similar conclusions, suggesting a pertinent bias that understates the home team. This study shows that the bias is changing over time, has a seasonal component, and is different relative to the spread of a football game.

Betting on the home-underdog is well documented betting strategy, but it is not strong enough to overcome bookie vigorish at a 90% confidence level. Betting on the home team, regardless of the spread, yields a higher winning percentage (55.23%) but is still not enough to significantly overcome a 10% takeout. Betting on the home team the day before the full moon, during the last 4 weeks of the season, has a winning percentage of 63.75% and is significant at all levels. The most profitable strategy, with a winning percentage of 76.47%, is betting on the home-underdog on the day before the full moon, late in the season.[30]

The study suggest that the inefficiencies that are being created on the day before the full moon may be caused by steroid usage in the league, but more data and research is needed to confirm this hypothesis. Although the possible synergistic interaction between the lunar cycle and steroid usage is very intriguing, there are other possible explanations for the full moon effect. It could be changes in the behavior of the fans, the officials, the bettors, the bookies, the home team, the visiting team, the coaches, or some combination of any of these groups that are causing this variation.

Explaining the timing of the lunar effect that is taking place goes beyond the scope of this study. For example, why is there such a pronounced bias on the day before the full moon and no effect on the day after a full moon? And why has the full moon effect recently intensified? The lunar effect occurring on the day before the full moon is beyond professional football, as it may affect humans on a broader level. National Football League wagering may just be a microcosm of the disturbances that the lunar cycle may create on all of us as human beings.

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[30] Only 17 observations, but significant at a 95% confidence level.

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