Sports Analytics and Data Science

Winning the Game with Methods and Models

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Preface

"Sometimes you win, sometimes you lose, sometimes it rains."

—TIM ROBBINS AS EBBY CALVIN LALOOSH IN *Bull Durham* (1988)

Businesses attract customers, politicians persuade voters, websites cajole visitors, and sports teams draw fans. Whatever the goal or target, data and models rule the day.

This book is about building winning teams and successful sports businesses. Winning and success are more likely when decisions are guided by data and models. Sports analytics is a source of competitive advantage.

This book provides an accessible guide to sports analytics. It is written for anyone who needs to know about sports analytics, including players, managers, owners, and fans. It is also a resource for analysts, data scientists, and programmers. The book views sports analytics in the context of data science, a discipline that blends business savvy, information technology, and modeling techniques.

To use analytics effectively in sports, we must first understand sports—the industry, the business, and what happens on the fields and courts of play. We need to know how to work with data—identifying data sources, gathering data, organizing and preparing them for analysis. We also need to know how to build models from data. Data do not speak for themselves. Useful predictions do not arise out of thin air. It is our job to learn from data and build models that work.

The best way to learn about sports analytics and data science is through examples. We provide a ready resource and reference guide for modeling techniques. We show programmers how to solve real world problems by building on a foundation of trustworthy methods and code.

The truth about what we do is in the programs we write. The code is there for everyone to see and for some to debug. Data sets and computer programs are available from the website for the *Modeling Techniques* series at `http://www.ftpress.com/miller/`. There is also a GitHub site at `https://github.com/mtpa/`.

When working on sports problems, some things are more easily accomplished with R, others with Python. And there are times when it is good to offer solutions in both languages, checking one against the other.

One of the things that distinguishes this book from others in the area of sports analytics is the range of data sources and topics discussed. Many researchers focus on numerical performance data for teams and players. We take a broader view of sports analytics—the view of data science. There are text data as well as numeric data. And with the growth of the World Wide Web, the sources of data are plentiful. Much can be learned from public domain sources through crawling and scraping the web and utilizing application programming interfaces (APIs).

I learn from my consulting work with professional sports organizations. Research Publishers LLC with its ToutBay division promotes what can be called "data science as a service." Academic research and models can take us only so far. Eventually, to make a difference, we need to implement our ideas and models, sharing them with one another.

Many have influenced my intellectual development over the years. There were those good thinkers and good people, teachers and mentors for whom I will be forever grateful. Sadly, no longer with us are Gerald Hahn Hinkle in philosophy and Allan Lake Rice in languages at Ursinus College, and Herbert Feigl in philosophy at the University of Minnesota. I am also most thankful to David J. Weiss in psychometrics at the University of Minnesota and Kelly Eakin in economics, formerly at the University of Oregon.

My academic home is the Northwestern University School of Professional Studies. Courses in sports research methods and quantitative analysis, marketing analytics, database systems and data preparation, web and network data science, web information retrieval and real-time analytics, and data visualization provide inspiration for this book. Thanks to the many students and fellow faculty from whom I have learned. And thanks to colleagues and staff who administer excellent graduate programs, including the Master of Science in Predictive Analytics, Master of Arts in Sports Administration, Master of Science in Information Systems, and the Advanced Certificate in Data Science.

Lorena Martin reviewed this book and provided valuable feedback while she authored a companion volume on sports performance measurement and analytics (Martin 2016). Adam Grossman and Tom Robinson provided valuable feedback about coverage of topics in sports business management. Roy Sanford provided advice on statistics. Amy Hendrickson of TEXnology Inc. applied her craft, making words, tables, and figures look beautiful in print—another victory for open source. Candice Bradley served dual roles as a reviewer and copyeditor for all books in the *Modeling Techniques* series. And Andy Beaster helped in preparing this book for final production. I am grateful for their guidance and encouragement.

Thanks go to my editor, Jeanne Glasser Levine, and publisher, Pearson/FT Press, for making this book possible. Any writing issues, errors, or items of unfinished business, of course, are my responsibility alone.

My good friend Brittney and her daughter Janiya keep me company when time permits. And my son Daniel is there for me in good times and bad, a friend for life. My greatest debt is to them because they believe in me.

Thomas W. Miller
Glendale, California
October 2015

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1 Understanding Sports Markets

"Those of you on the floor at the end of the game, I'm proud of you. You played your guts out. I'm only going to say this one time. All of you have the weekend. Think about whether or not you want to be on this team under the following condition: What I say when it comes to this basketball team is the law, absolutely and without discussion."

—Gene Hackman as Coach Norman Dale in *Hoosiers* (1986)

In applying the laws of economics to professional sports, we must consider the nature of sports and the motives of owners. Professional sports are different from other forms of business.

There are sellers and buyers of sports entertainment. The sellers are the players and teams within the leagues of professional sports. The buyers are consumers of sports, many of whom never go to games in person but who watch sports on television, listen to the radio, and buy sports team paraphernalia.

Sports compete with other forms of entertainment for people's time and money. And various sports compete with one another, especially when their seasons overlap. Sports teams produce entertainment content that is distributed through the media. Sports teams license their brand names and logos to other organizations, including sports apparel manufacturers.

Sports teams are not independent businesses competing with one another. While players and teams compete on the fields and courts of play, they cooperate with one another as members of leagues. The core product of sports is the sporting contest, a joint product of two or more players or two or more teams.

Fifty-four sports and recreation activities, shown in table 1.1, are tracked by the National Sporting Goods Association (2015), which serves the sporting goods industry. In recent years, participation in baseball, basketball, football, and tennis has declined, while participation in soccer has increased. There has been growth in individual recreational sports, such as skateboarding and snowboarding. Of course, levels of participation in sports are not necessarily an indicator of levels of interest in sports as entertainment.

Sports businesses produce entertainment products by cooperating with one another. While it is illegal for businesses in most industries to collude in setting output and prices, sports leagues engage in cooperative output and pricing as a standard part of their business model. The number of games, indeed the entire schedule of games in a sport, is determined by the league. In fact, aspects of professional sports are granted monopoly power by the federal government in the United States.

When developing a model for a typical business or firm, an economist would assume profit maximization as a motive. But for a professional sports team, an owner's motives may not be so easily understood. While one owner may operate his or her team for profit year by year, another may seek to maximize wins or overall utility. Another may look for capital appreciation—buying, then selling after a few years. Lacking knowledge of owners' motives, it is difficult to predict what they will do.

Gaining market share and becoming the dominant player is a goal of firms in many industries. Not so in the business of professional sports. If one team were assured of victory in almost all of its contests, interest in those contests could wane. A team benefits by winning more often than losing, but winning all the time may be less beneficial than winning most of the time. Professional sports leagues claim to be seeking competitive balance, although there are dominant teams in many leagues.

Table 1.1. *Sports and Recreation Activities in the United States*

Aerobic Exercising	Ice/Figure Skating
Archery (Target)	In-Line Roller Skating
Backpack/Wilderness Camping	Kayaking
Baseball	Lacrosse
Basketball	Martial Arts/MMA/Tae Kwon Do
Bicycle Riding	Mountain Biking (Off Road)
Billiards/Pool	Muzzleloading
Boating (Motor/Power)	Paintball Games
Bowling	Running/Jogging
Boxing	Scuba Diving (Open Water)
Camping (Vacation/Overnight)	Skateboarding
Canoeing	Skiing (Alpine)
Cheerleading	Skiing (Cross Country)
Dart Throwing	Snowboarding
Exercise Walking	Soccer
Exercising with Equipment	Softball
Fishing (Fresh Water)	Swimming
Fishing (Salt Water)	Table Tennis/Ping Pong
Football (Flag)	Target Shooting (Airgun)
Football (Tackle)	Target Shooting (Live Ammunition)
Football (Touch)	Tennis
Golf	Volleyball
Gymnastics	Water Skiing
Hiking	Weight Lifting
Hockey (Ice)	Work Out at Club/Gym/Fitness Studio
Hunting with Bow & Arrow	Wrestling
Hunting with Firearms	Yoga

Sports is big business as shown by valuations and finances of the major professional sports in the United States and worldwide. Data from *Forbes* for Major League Baseball (MLB), the National Basketball Association (NBA), the National Football League (NFL), and worldwide soccer teams are shown in tables 1.2 through 1.5.

Professional sports teams most certainly compete with one another in the labor market, and labor in the form of star players is in short supply. Some argue that salary caps are necessary to preserve competitive balance. Salary caps also help teams in limiting expenditures on players.

Most professional sports in the United States have salary caps. The 2015 salary cap for NFL teams, with fifty-three player rosters, is set at $143.28 million (Patra 2015). Most teams have payrolls at or near the cap, making the average salary of an NFL player about $2.7 million. One player on an NFL team may be designated as a *franchise player*, restricting that player from entering free agency. The league sets minimum salaries for franchise players. For example, a franchise quarterback has a minimum salary of $18.544 million in 2015. The highest annual salary among NFL players is $22 million for Aaron Rodgers, Green Bay Packers quarterback (spotrac 2015c). The minimum annual salary is $420 thousand.

NBA teams have a $70 million salary cap for the 2015–16 season, with penalties for teams going over the cap. Maximum player salaries are based on a percentage of cap and years of service. For example, LeBron James, with ten years of experience, would have a maximum salary of $23 million (Mahoney 2015). New Orleans Pelicans Anthony Davis' average salary of $29 million is the highest among NBA players (spotrac 2015b). Team rosters include fifteen players under contract, with as many as thirteen available to play in any particular game. The minimum annual salary is $428,498.

Major League Baseball (MLB) has a "luxury tax" for teams with payrolls in excess of $189 million. There is a regular-player roster of twenty-five or twenty-six players for double-header days/nights. A forty-man roster includes players under contract and eligible to play. Between September 1 and the end of the regular season the roster is expanded to forty players. The roster drops back to twenty-five players for the playoffs. The minimum MLB annual salary is $505,700 in 2015. The highest MLB annual salary is $31 million for Miguel Cabrera of the Detroit Tigers (spotrac 2015a).

Table 1.2. *MLB Team Valuation and Finances (March 2015)*

Team Rank	Team	Current Value ($ Millions)	One-Year Change in Value (Percentage)	Debt/Value (Percentage)	Revenue ($ Millions)	Operating Income ($ Millions)
1	New York Yankees	3,200	28	0	508	8.1
2	Los Angeles Dodgers	2,400	20	17	403	-12.2
3	Boston Red Sox	2,100	40	0	370	49.2
4	San Francisco Giants	2,000	100	4	387	68.4
5	Chicago Cubs	1,800	50	24	302	73.3
6	St Louis Cardinals	1,400	71	21	294	73.6
7	New York Mets	1,350	69	26	263	25.0
8	Los Angeles Angels	1,300	68	0	304	16.7
9	Washington Nationals	1,280	83	27	287	41.4
10	Philadelphia Phillies	1,250	28	8	265	-39.0
11	Texas Rangers	1,220	48	13	266	3.5
12	Atlanta Braves	1,150	58	0	267	33.2
13	Detroit Tigers	1,125	65	15	254	-20.7
14	Seattle Mariners	1,100	55	0	250	26.4
15	Baltimore Orioles	1,000	61	15	245	31.4
16	Chicago White Sox	975	40	5	227	31.9
17	Pittsburgh Pirates	900	57	10	229	43.6
18	Minnesota Twins	895	48	25	223	21.3
19	San Diego Padres	890	45	22	224	35.0
20	Cincinnati Reds	885	48	6	227	2.2
21	Milwaukee Brewers	875	55	6	226	11.3
22	Toronto Blue Jays	870	43	0	227	-17.9
23	Colorado Rockies	855	49	7	214	12.6
24	Arizona Diamondbacks	840	44	17	211	-2.2
25	Cleveland Indians	825	45	9	207	8.9
26	Houston Astros	800	51	34	175	21.6
27	Oakland Athletics	725	46	8	202	20.8
28	Kansas City Royals	700	43	8	231	26.6
29	Miami Marlins	650	30	34	188	15.4
30	Tampa Bay Rays	625	29	22	188	7.9

Source. Badenhausen, Ozanian, and Settimi (2015b).

Table 1.3. NBA Team Valuation and Finances (January 2015)

Team Rank	Team	Current Value ($ Millions)	One-Year Change in Value (Percentage)	Debt/Value (Percentage)	Revenue ($ Millions)	Operating Income ($ Millions)
1	Los Angeles Lakers	2,600	93	2	293	104.1
2	New York Knicks	2,500	79	0	278	53.4
3	Chicago Bulls	2,000	100	3	201	65.3
4	Boston Celtics	1,700	94	9	173	54.9
5	Los Angeles Clippers	1,600	178	0	146	20.1
6	Brooklyn Nets	1,500	92	19	212	-99.4
7	Golden State Warriors	1,300	73	12	168	44.9
8	Houston Rockets	1,250	61	8	175	38.0
9	Miami Heat	1,175	53	8	188	12.6
10	Dallas Mavericks	1,150	50	17	168	30.4
11	San Antonio Spurs	1,000	52	8	172	40.9
12	Portland Trail Blazers	940	60	11	153	11.7
13	Oklahoma City Thunder	930	58	15	152	30.8
14	Toronto Raptors	920	77	16	151	17.9
15	Cleveland Cavaliers	915	78	22	149	20.6
16	Phoenix Suns	910	61	20	145	28.2
17	Washington Wizards	900	86	14	143	10.1
18	Orlando Magic	875	56	17	143	20.9
19	Denver Nuggets	855	73	1	136	14.0
20	Utah Jazz	850	62	6	142	32.7
21	Indiana Pacers	830	75	18	139	25.0
22	Atlanta Hawks	825	94	21	133	14.8
23	Detroit Pistons	810	80	23	144	17.6
24	Sacramento Kings	800	45	29	125	8.9
25	Memphis Grizzlies	750	66	23	135	10.5
26	Charlotte Hornets	725	77	21	130	1.2
27	Philadelphia 76ers	700	49	21	125	24.4
28	New Orleans Pelicans	650	55	19	131	19.0
29	Minnesota Timberwolves	625	45	16	128	6.9
30	Milwaukee Bucks	600	48	29	110	11.5

Source. Badenhausen, Ozanian, and Settimi (2015a).

Table 1.4. *NFL Team Valuation and Finances (August 2014)*

Team Rank	Team	Current Value ($ Millions)	One-Year Change in Value (Percentage)	Debt/Value (Percentage)	Revenue ($ Millions)	Operating Income ($ Millions)
1	Dallas Cowboys	3,200	39	6	560	245.7
2	New England Patriots	2,600	44	9	428	147.2
3	Washington Redskins	2,400	41	10	395	143.4
4	New York Giants	2,100	35	25	353	87.3
5	Houston Texans	1,850	28	11	339	102.8
6	New York Jets	1,800	30	33	333	79.5
7	Philadelphia Eagles	1,750	33	11	330	73.2
8	Chicago Bears	1,700	36	6	309	57.1
9	San Francisco 49ers	1,600	31	53	270	24.8
10	Baltimore Ravens	1,500	22	18	304	56.7
11	Denver Broncos	1,450	25	8	301	30.7
12	Indianapolis Colts	1,400	17	4	285	60.7
13	Green Bay Packers	1,375	16	1	299	25.6
14	Pittsburgh Steelers	1,350	21	15	287	52.4
15	Seattle Seahawks	1,330	23	9	288	27.3
16	Miami Dolphins	1,300	21	29	281	8.0
17	Carolina Panthers	1,250	18	5	283	55.6
18	Tampa Bay Buccaneers	1,225	15	15	275	46.4
19	Tennessee Titans	1,160	10	11	278	35.6
20	Minnesota Vikings	1,150	14	43	250	5.3
21	Atlanta Falcons	1,125	21	27	264	13.1
22	Cleveland Browns	1,120	11	18	276	35.0
23	New Orleans Saints	1,110	11	7	278	50.1
24	Kansas City Chiefs	1,100	9	6	260	10.0
25	Arizona Cardinals	1,000	4	15	266	42.8
26	San Diego Chargers	995	5	10	262	39.9
27	Cincinnati Bengals	990	7	10	258	11.9
28	Oakland Raiders	970	18	21	244	42.8
29	Jacksonville Jaguars	965	15	21	263	56.9
30	Detroit Lions	960	7	29	254	-15.9
31	Buffalo Bills	935	7	13	252	38.0
32	St Louis Rams	930	6	12	250	16.2

Source. Badenhausen, Ozanian, and Settimi (2014).

Table 1.5. *World Soccer Team Valuation and Finances (May 2015)*

Team Rank	Team	Current Value ($ Millions)	One-Year Change in Value (Percentage)	Debt/Value (Percentage)	Revenue ($ Millions)	Operating Income ($ Millions)
1	Real Madrid	3,263	-5	4	746	170
2	Barcelona	3,163	-1	3	657	174
3	Manchester United	3,104	10	20	703	211
4	Bayern Munich	2,347	27	0	661	78
5	Manchester City	1,375	59	0	562	122
6	Chelsea	1,370	58	0	526	83
7	Arsenal	1,307	-2	30	487	101
8	Liverpool	982	42	10	415	86
9	Juventus	837	-2	9	379	50
10	AC Milan	775	-10	44	339	54
11	Borussia Dortmund	700	17	6	355	55
12	Paris Saint-Germain	634	53	0	643	-1
13	Tottenham Hotspur	600	17	9	293	63
14	Schalke 04	572	-1	0	290	57
15	Inter Milan	439	-9	56	222	-41
16	Atletico de Madrid	436	33	53	231	47
17	Napoli	353	19	0	224	43
18	Newcastle United	349	33	0	210	44
19	West Ham United	309	33	12	186	54
20	Galatasaray	294	-15	17	220	-37

Source. Ozanian (2015).

Figure 1.1, a histogram lattice, shows how player salaries compare across the MLB, NBA, and NFL in August 2015. Player salary distributions are positively skewed. The mean salary across NFL players is around $1.7 million, but the median is $630 thousand. The mean salary across NBA players is around $5.1 million, with median salary $2.8 million. The mean salary across MLB players is around $4.1 million, with the median $1.1 million.

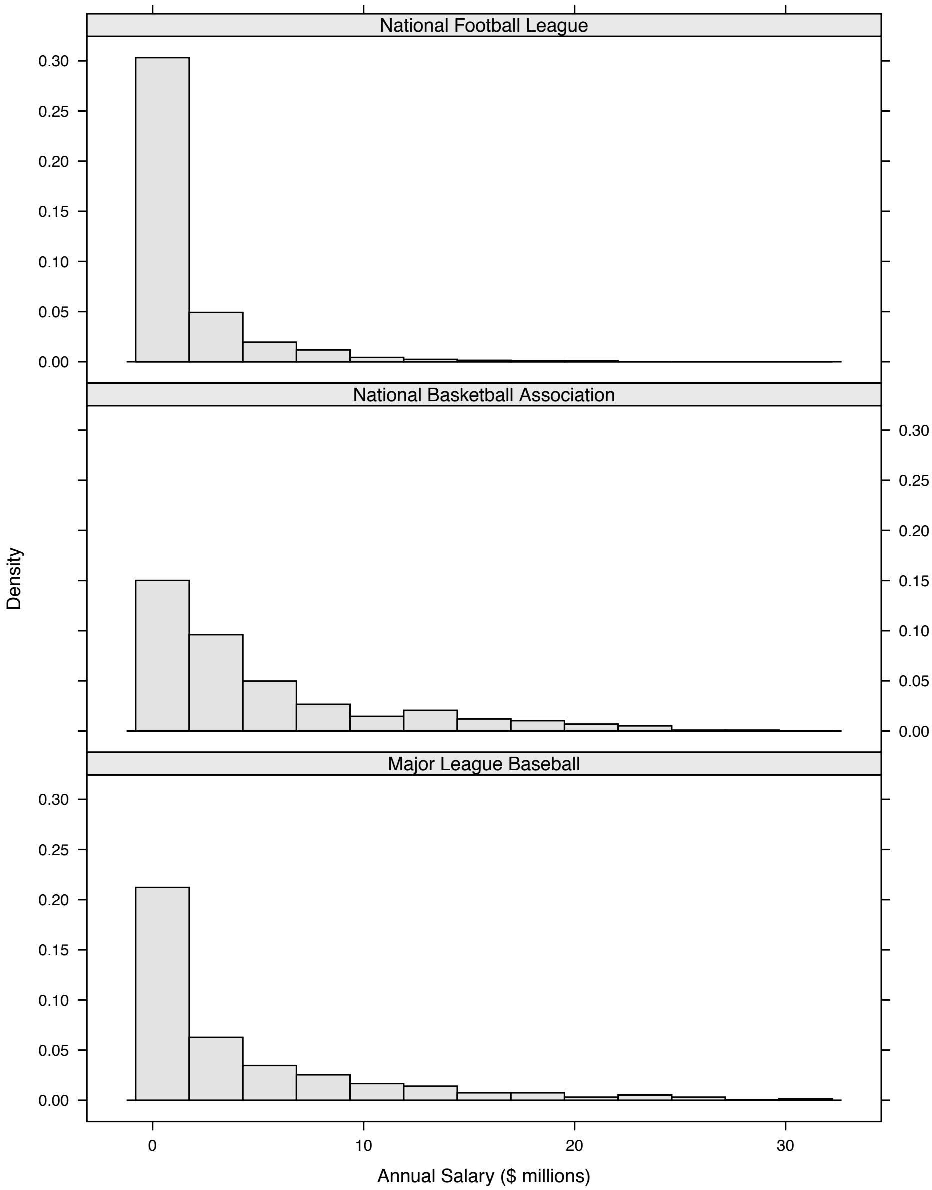
Do team expenditures on players buy success? This is a meaningful question to ask for leagues that have no salary caps. Szymanski (2015) reports studies showing that between 60 and 90 percent of the variability in U.K. soccer team positions may be explained by wages paid to players. Major League Baseball has a luxury tax in place of a salary cap, and team payrolls vary widely in size. The New York Yankees have been known for having the highest payrolls in baseball. Recently, the Los Angeles Dodgers have surpassed the Yankees with the highest player payroll—more than $257 million at the end of the 2014 season (Woody 2014).

Figure 1.2 shows baseball team salaries at the beginning of the 2014 season plotted against the percentage of games won across the regular season. Notice how teams that made the playoffs in 2014, labeled with team abbreviations, have a wide range of payrolls. While the biggest spenders in baseball are often among the set of teams going to the playoffs, the relationship between team payrolls and team performance is weak at best—less than 7 percent of the variability in win/loss percentages is explained by player payrolls.

The thesis of Michael Lewis' *Moneyball* (2003) and what has become the ethos of sports analytics is that small-market baseball teams can win by spending their money wisely. Star players demand top salaries due as much to their celebrity status as to their skills. Players with high on-base percentages, overlooked by major-market teams, can be hired at much lower salaries than star players.

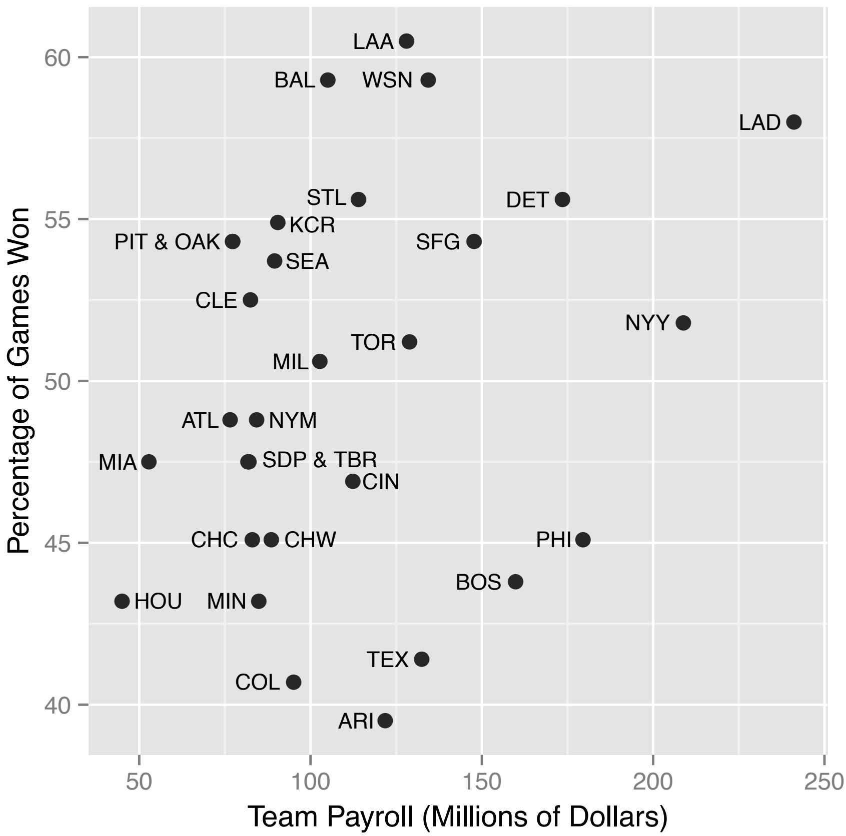
Teams, although associated with particular cities, can be known nationwide or worldwide. The media of television and the Internet provide opportunities for reaching consumers across the globe. A Super Bowl at the Rose Bowl in Pasadena, California or AT&T Stadium in Arlington, Texas may be attended by around 100 thousand fans (Alder 2015), while U.S. television audiences have grown to over 100 million (statista 2015).

Figure 1.1. *MLB, NBA, and NFL Average Annual Salaries*



Sources. spotrac (2015a, 2015b, 2015c).

Figure 1.2. MLB Team Payrolls and Win/Loss Performance (2014 Season)



Sources. Sports Reference LLC (2015b) and USA Today (2015).

See Appendix B, page 255, for team abbreviations and names.

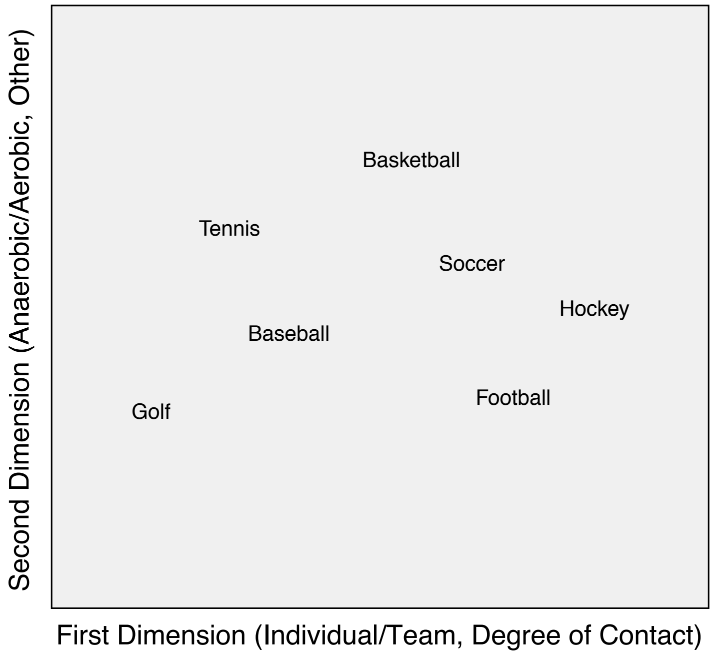
Media revenues are important to successful sports teams. Other revenues come from business partnerships, sponsorships, advertising, and stadium naming rights. City governments understand well the power of sports to promote business. Locating sports arenas in cities can help to revitalize downtown areas, as demonstrated by the experience of the Oklahoma City Thunder. Indianapolis, Indiana promotes itself as a sports capital with the Colts and Pacers (Rein, Shields, and Grossman 2015).

Teams seek to build their brands, developing a positive reputation in the minds of consumers. Players, like fans, are attracted to teams with a reputation for hard work, courage, fair play, honesty, teamwork, and community service. The character of a team is often as important as its likelihood of winning. The Cubs are associated with Chicago, but Cub fans may be found from Maine to California. This is despite the fact that the Cubs have not won the World Series since 1908. Teams in U.S. professional sports vie to become "America's team," with fans across the land wearing their logo-embossed hats and jerseys.

The demand for sports and the feelings of sports consumers are not so easily understood. Fans can be fickle and fandom fleeting. Fans can be loyal to a sport, to a team, or to individual players. Multivariate methods can help us understand how sports consumers think by revealing relationships among products or brands.

Figure 1.3 provides an example, a *perceptual map* of seven sports. Along the horizontal dimension, we move from individual, non-contact sports on the left-hand side, to team sports with little contact, to team sports with contact on the right-hand side. The vertical dimension, less easily described, may be thought of as relating to the aerobic versus anaerobic nature of sports and to other characteristics such as physicality and skill. Sports such as tennis, soccer, and basketball entail aerobic exercise. These are endurance sports, while football is an example of a sport that involves both aerobic and anaerobic exercise, including intense exercise for short durations. Sports close together on the map have similarities. Baseball and golf, for example, involve special skills, such as precision in hitting a ball. Soccer and hockey involve almost continuous movement and getting a ball through the goal. Football and hockey have high physicality or player contact.

Figure 1.3. *A Perceptual Map of Seven Sports*



In many respects, professional sports teams are decidedly different from other businesses. They are in the public eye. They live and die in the media. And a substantial portion of their revenues come from media.

Késenne (2007), Szymanski (2009), Fort (2011), Fort and Winfree (2013), Leeds and von Allmen (2014), and the edited volumes of Humphreys and Howard (2008a, 2008b, 2008c) review sports economics and business issues.

Gorman and Calhoun (1994) and Rein, Shields, and Grossman (2015) focus on alternative sources of revenue for sports teams and how these relate to business strategy. The business of baseball has been the subject of numerous volumes (Miller 1990; Zimbalist 1992; Powers 2003; Bradbury 2007; Pessah 2015). And Jozsa (2010) reviews the history of the National Basketball Association.

An overview of sports marketing is provided by Mullin, Hardy, and Sutton (2014). Rein, Kotler, and Shields (2006) and Carter (2011) discuss the convergence of entertainment and sports. Miller (2015a) reviews methods in marketing data science, including product positioning maps, market segmentation, target marketing, customer relationship management, and competitive analysis.

Sports also represents a laboratory for labor market research. Sports is one of the few industries in which job performance and compensation are public knowledge. Economic studies examine player performance measures and value of individual players to teams (Kahn 2000; Bradbury 2007). Miller (1991), Abrams (2010), and Lowenfish (2010) review baseball labor relations. And Early (2011) provides insight into labor and racial discrimination in professional sports.

Sports wagering markets have been studied extensively by economists because they provide public information about price, volume, and rates of return. Furthermore, sports betting opportunities have fixed beginning and ending times and published odds or point spreads, making them easier to study than many financial investment opportunities. As a result, sports wagering markets have become a virtual field laboratory for the study of market efficiency. Sauer (1998) provides a comprehensive review of the economics of wagering markets.

When management objectives can be defined clearly in mathematical terms, teams use mathematical programming methods—constrained optimization. Teams attempt to maximize revenue or minimize costs subject to known situational factors. There has been extensive work on league schedules, for which the league objective may be to have teams playing one another an equal number of times while minimizing total distance traveled between cities. Alternatively, league officials may seek home/away schedules, revenue sharing formulas, or draft lottery rules that maximize competitive balance. Briskorn (2008) reviews methods for scheduling sports competition, drawing on integer programming, combinatorics, and graph theory. Wright (2009) provides an overview of operations research in sport.

Extensive data about sports are in the public domain, readily available in newspapers and online sources. These data offer opportunities for predictive modeling and research. Throughout the book we also identify places to apply methods of operations research, including mathematical programming and simulation.

Exhibit 1.1 shows an R program for exploring distributions of player salaries across the MLB, NBA, and NFL. The program draws on software for statistical graphics from Sarkar (2008).

Exhibit 1.2 (page 18) shows an R program for examining the relationship between MLB payrolls and win-loss performance. The program draws on software for statistical graphics from Wickham and Chang (2014).

Exhibit 1.3 (page 19) shows an R program to obtain a perceptual map of seven sports, showing their relationships with one another. The program draws on modeling software for multidimensional scaling.

Exhibit 1.1. *MLB, NBA, and NFL Player Salaries (R)*

```
# MLB, NBA, and NFL Player Salaries (R)

library(lattice)  # statistical graphics

# variables in contract data from spotrac.com (August 2015)
#   player: player name (contract years)
#   position: position on team
#   team: team abbreviation
#   teamsignedwith: team that signed the original contract
#   age: age in years as of August 2015
#   years:  years as player in league
#   contract: dollars in contract
#   guaranteed: guaranteed dollars in contract
#   guaranteedpct: percentage of contract dollars guaranteed
#   salary: annual salary in dollares
#   yearfreeagent: year player becomes free agent
#
#   additional created variables
#   salarymm: salary in millions
#   leaguename: full league name
#   league: league abbreviation

# read data for Major League Baseball
mlb_contract_data <- read.csv("mlb_player_salaries_2015.csv")
mlb_contract_data$leaguename <- rep("Major League Baseball",
    length = nrow(mlb_contract_data))
for (i in seq(along = mlb_contract_data$yearfreeagent))
    if (mlb_contract_data$yearfreeagent[i] == 0)
        mlb_contract_data$yearfreeagent[i] <- NA
for (i in seq(along = mlb_contract_data$age))
    if (mlb_contract_data$age[i] == 0)
        mlb_contract_data$age[i] <- NA
mlb_contract_data$salarymm <- mlb_contract_data$salary/1000000
mlb_contract_data$league <- rep("MLB", length = nrow(mlb_contract_data))
print(summary(mlb_contract_data))
# variables for plotting
mlb_data_plot <- mlb_contract_data[, c("salarymm","leaguename")]

nba_contract_data <- read.csv("nba_player_salaries_2015.csv")
nba_contract_data$leaguename <- rep("National Basketball Association",
    length = nrow(nba_contract_data))
for (i in seq(along = nba_contract_data$yearfreeagent))
    if (nba_contract_data$yearfreeagent[i] == 0)
        nba_contract_data$yearfreeagent[i] <- NA
for (i in seq(along = nba_contract_data$age))
    if (nba_contract_data$age[i] == 0)
        nba_contract_data$age[i] <- NA
nba_contract_data$salarymm <- nba_contract_data$salary/1000000
nba_contract_data$league <- rep("NBA", length = nrow(nba_contract_data))
print(summary(nba_contract_data))
```

```
# variables for plotting
nba_data_plot <- nba_contract_data[, c("salarymm","leaguename")]

nfl_contract_data <- read.csv("nfl_player_salaries_2015.csv")
nfl_contract_data$leaguename <- rep("National Football League",
    length = nrow(nfl_contract_data))
for (i in seq(along = nfl_contract_data$yearfreeagent))
    if (nfl_contract_data$yearfreeagent[i] == 0)
        nfl_contract_data$yearfreeagent[i] <- NA
for (i in seq(along = nfl_contract_data$age))
    if (nfl_contract_data$age[i] == 0)
        nfl_contract_data$age[i] <- NA
nfl_contract_data$salarymm <- nfl_contract_data$salary/1000000
nfl_contract_data$league <- rep("NFL", length = nrow(nfl_contract_data))
print(summary(nfl_contract_data))
# variables for plotting
nfl_data_plot <- nfl_contract_data[, c("salarymm","leaguename")]

# merge contract data with variables for plotting
plotting_data_frame <- rbind(mlb_data_plot, nba_data_plot, nfl_data_plot)

# generate the histogram lattice for comparing player salaries
# across the three leagues in this study
lattice_object <- histogram(~salarymm | leaguename, plotting_data_frame,
    type = "density", xlab = "Annual Salary ($ millions)", layout = c(1,3))

# print to file
pdf(file = "fig_understanding_markets_player_salaries.pdf",
     width = 8.5, height = 11)
print(lattice_object)
dev.off()
```

Exhibit 1.2. *Payroll and Performance in Major League Baseball (R)*

```
# Payroll and Performance in Major League Baseball (R)

library(ggplot2)  # statistical graphics

# functions used with grid graphics to split the plotting region
# to set margins and to plot more than one ggplot object on one page/screen
vplayout <- function(x, y)
viewport(layout.pos.row=x, layout.pos.col=y)

# user-defined function to plot a ggplot object with margins
ggplot.print.with.margins <- function(ggplot.object.name,
    left.margin.pct=10,
     right.margin.pct=10,top.margin.pct=10,bottom.margin.pct=10)
    { # begin function for printing ggplot objects with margins
      # margins expressed as percentages of total... use integers
    grid.newpage()
    pushViewport(viewport(layout=grid.layout(100,100)))
    print(ggplot.object.name,
    vp=vplayout((0 + top.margin.pct):(100 - bottom.margin.pct),
        (0 + left.margin.pct):(100 - right.margin.pct)))
    } # end function for printing ggplot objects with margins

# read in payroll and performance data
# including annotation text for team abbreviations
mlb_data <- read.csv("mlb_payroll_performance_2014.csv")
mlb_data$millions <- mlb_data$payroll/1000000
mlb_data$winpercent <- mlb_data$wlpct * 100

cat("\nCorrelation between Payroll and Performance:\n")
with(mlb_data, print(cor(millions, winpercent)))

cat("\nProportion of win/loss percentage explained by payrolls:\n")
with(mlb_data, print(cor(millions, winpercent)^2))

pdf(file = "fig_understanding_markets_payroll_performance.pdf",
     width = 5.5, height = 5.5)
ggplot_object <- ggplot(data = mlb_data,
    aes(x = millions, y = winpercent)) +
    geom_point(colour = "darkblue", size = 3) +
    xlab("Team Payroll (Millions of Dollars)") +
    ylab("Percentage of Games Won") +
    geom_text(aes(label = textleft), size = 3, hjust = 1.3) +
    geom_text(aes(label = textright), size = 3, hjust = -0.25)

ggplot.print.with.margins(ggplot_object, left.margin.pct = 5,
    right.margin.pct = 5, top.margin.pct = 5, bottom.margin.pct = 5)

dev.off()
```

Exhibit 1.3. *Making a Perceptual Map of Sports (R)*

```
# Making a Perceptual Map of Sports (R)

library(MASS)  # includes functions for multidimensional scaling
library(wordcloud)  # textplot utility to avoid overlapping text

USE_METRIC_MDS <- FALSE  # metric versus non-metric toggle

# utility function for converting a distance structure
# to a distance matrix as required for some routines and
# for printing of the complete matrix for visual inspection.
make.distance.matrix <- function(distance_structure)
    { n <- attr(distance_structure, "Size")
      full <- matrix(0,n,n)
      full[lower.tri(full)] <- distance_structure
      full+t(full)
    }

# enter data into a distance structure as required for various
# distance-based routines. That is, we enter the upper triangle
# of the distance matrix as a single vector of distances
distance_structure <-
    as.single(c(9,11,10,5,14,4,15,6,12,13,16,1,18,2,20,7,3,19,17,8,21))

# provide a character vector of sports names
sport_names <- c("Baseball", "Basketball", "Football",
    "Soccer", "Tennis", "Hockey", "Golf")

attr(distance_structure, "Size") <- length(sport_names)  # set size attribute

# check to see that the distance structure has been entered correctly
# by converting the distance structure to a distance matrix
# using the utility function make.distance.matrix, which we had defined
distance_matrix <- unlist(make.distance.matrix(distance_structure))
cat("\n","Distance Matrix of Seven Sports","\n")
print(distance_matrix)

if (USE_METRIC_MDS)
    {
    # apply the metric multidimensional scaling algorithm and plot the map
    mds_solution <- cmdscale(distance_structure, k=2, eig=T)
    }

# apply the non-metric multidimensional scaling algorithm
# this is more appropriate for rank-order data
# and provides a more satisfactory solution here

if (!USE_METRIC_MDS)
    {
    mds_solution <- isoMDS(distance_matrix, k = 2, trace = FALSE)

    }
```

```
pdf(file = "plot_nonmetric_mds_seven_sports.pdf",
    width=8.5, height=8.5) # opens pdf plotting device
# use par(mar = c(bottom, left, top, right)) to set up margins on the plot
par(mar=c(7.5, 7.5, 7.5, 5))

# original solution
First_Dimension <- mds_solution$points[,1]
Second_Dimension <- mds_solution$points[,2]

# set up the plot but do not plot points... use names for points
plot(First_Dimension, Second_Dimension, type = "n", cex = 1.5,
    xlim = c(-15, 15), ylim = c(-15, 15))  # first page of pdf plots
# We plot the sport names in the locations where points normally go.
text(First_Dimension, Second_Dimension, labels = sport_names,
    offset = 0.0, cex = 1.5)
title("Seven Sports (initial solution)")

# reflect the horizontal dimension
# multiply the first dimension by -1 to get reflected image
First_Dimension <- mds_solution$points[,1] * -1
Second_Dimension <- mds_solution$points[,2]
plot(First_Dimension, Second_Dimension, type = "n", cex = 1.5,
    xlim = c(-15, 15), ylim = c(-15, 15))  # second page of pdf plots
text(First_Dimension, Second_Dimension, labels = sport_names,
    offset = 0.0, cex = 1.5)
title("Seven Sports (horizontal reflection)")

# reflect the vertical dimension
# multiply the section dimension by -1 to get reflected image
First_Dimension <- mds_solution$points[,1]
Second_Dimension <- mds_solution$points[,2] * -1
plot(First_Dimension, Second_Dimension, type = "n", cex = 1.5,
    xlim = c(-15, 15), ylim = c(-15, 15))  # third page of pdf plots
text(First_Dimension, Second_Dimension, labels = sport_names,
    offset = 0.0, cex = 1.5)
title("Seven Sports (vertical reflection)")

# multiply the first and second dimensions by -1
# for reflection in both horizontal and vertical directions
First_Dimension <- mds_solution$points[,1] * -1
Second_Dimension <- mds_solution$points[,2] * -1
plot(First_Dimension, Second_Dimension, type = "n", cex = 1.5,
    xlim = c(-15, 15), ylim = c(-15, 15))  # fourth page of pdf plots
text(First_Dimension, Second_Dimension, labels = sport_names,
    offset = 0.0, cex = 1.5)
title("Seven Sports (horizontal and vertical reflection)")
dev.off()  # closes the pdf plotting device

pdf(file = "plot_pretty_original_mds_seven_sports.pdf",
    width=8.5, height=8.5) # opens pdf plotting device
# use par(mar = c(bottom, left, top, right)) to set up margins on the plot
par(mar=c(7.5, 7.5, 7.5, 5))
```

```
First_Dimension <- mds_solution$points[,1]  # no reflection
Second_Dimension <- mds_solution$points[,2]   # no reflection
# wordcloud utility for plotting with no overlapping text
textplot(x = First_Dimension,
    y = Second_Dimension,
    words = sport_names,
    show.lines = FALSE,
    xlim = c(-15, 15),  # extent of horizontal axis range
    ylim = c(-15, 15),  # extent of vertical axis range
    xaxt = "n",  # suppress tick marks
    yaxt = "n",  # suppress tick marks
    cex = 1.15,  # size of text points
    mgp = c(0.85, 1, 0.85),  # position of axis labels
    cex.lab = 1.5,  # magnification of axis label text
    xlab = "",
    ylab = "")
dev.off()  # closes the pdf plotting device


pdf(file = "fig_sports_perceptual_map.pdf",
    width=8.5, height=8.5) # opens pdf plotting device
# use par(mar = c(bottom, left, top, right)) to set up margins on the plot
par(mar=c(7.5, 7.5, 7.5, 5))
First_Dimension <- mds_solution$points[,1] * -1  # reflect horizontal
Second_Dimension <- mds_solution$points[,2]
# wordcloud utility for plotting with no overlapping text
textplot(x = First_Dimension,
    y = Second_Dimension,
    words = sport_names,
    show.lines = FALSE,
    xlim = c(-15, 15),  # extent of horizontal axis range
    ylim = c(-15, 15),  # extent of vertical axis range
    xaxt = "n",  # suppress tick marks
    yaxt = "n",  # suppress tick marks
    cex = 1.15,  # size of text points
    mgp = c(0.85, 1, 0.85),  # position of axis labels
    cex.lab = 1.5,  # magnification of axis label text
    xlab = "First Dimension (Individual/Team, Degree of Contact)",
    ylab = "Second Dimension (Anaerobic/Aerobic, Other")
dev.off()  # closes the pdf plotting device
```

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